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ENTOMOLOGICAL PROBLEMS IN MALARIA CONTROL*

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Fellow members of the National Malaria Society, guests, ladies and gentlemen. First, I wish to thank the members of the Society for the honor shown me as a representative of the entomological fraternity in selecting me as president at a time when the malaria control work being done by the members of the Society and their associates is of such great importance.

It is gratifying to all of us that the remarkable progress made during this war period in extending our knowledge of malaria and in quickly applying this new knowledge to control procedures undoubtedly will mark an epoch in the long fight against this most important disease. There are, however, many points yet to be cleared before a full understanding of malaria, its vectors and their control can be claimed, even in the United States. It is concerning some of these that I have chosen to call attention.

There naturally are two lines of attack against malaria; namely, the attack on the parasite in man and the attack on the mosquito vector. The first of these, the attack on the parasite in it's human host undoubtedly is the logical approach, and remarkable progress is being made in this field. However, no therapeutic or immunologic method has yet been found which can be relied on to accomplish desired results. Therefore, at the present time at least, the attack on the mosquito vector still must be considered as the most promising approach. We know that without bites from infected anophelines, malaria cannot be perpetuated even though human carriers may be present in a community.

The attack on the mosquito vector is, of course, the one which concerns the entomologist. His problems in this connection are those involved discovering the details of anopheline biology and habits and in working out the application of this information in control practice. This work includes the accurate determination of

*Presidential address before National Malaria Society, St. Louis, Missouri, 16 November 1944.

the identity and abundance of the anophelines present in an area, the incrimination of those species which are transmitting malaria and in finding out their specific breeding, resting, flight, associational and other habits. The need for this specific knowledge is in no way lessened by the discovery of new insecticides which promise to revolutionize our anti-anopheline methods.

The determination of the specific identity of the anophelines present in an area often require a great amount of careful taxonomic study. The aim of this work is to clarify and thus simplify the epidemiological picture and not, as some suppose, to create new species by hair-splitting taxonomy which confuses the situation. The importance of this work cannot be illustrated better than by the classic example involving *Anopheles maculipennis* in Europe. *Maculipennis* was long considered a homogeneous species and a great deal of epidemiological study failed to explain why malaria was prevalent in certain parts of its range, while in others, under apparently similar conditions, there was little or no transmission. Careful systematic work revealed that *maculipennis* was not a homogeneous species, but one composed of six races or subspecies which could be separated by minute morphological differences in the egg stage. Each of the races had marked differences in ecology, host preference and ability to transmit malaria. With this information at hand the malaria puzzle was solved.

There have been several recent developments along this line in the United States. Careful studies of the nearctic *malculipennis* complex by Aitken (1) have resulted in the recognition of three distinct subspecies in North America, two of which, *freeborni* and *occidentalis,* occur in this country. Since epidemiological evidence indicates that of these only *freeborni* is concerned with malaria transmission in nature, it has been possible to limit war-time malaria prevention activities on the Pacific Coast to areas where only this species is abundant, thereby effecting a large saving in labor and materials.

For a long time it was thought that *A. pseudopunctipennis* was a homogeneous species. It was known to transmit malaria in South and Central America but not in the United States. This inconsistency was solved to a large extent by the finding that *pseudopunctipennis* could be separated into two subspecies: *franciscanus,* an apparently harmless form which is wide-spread in the western United States, and the true *pseudopunctipennis*, a noxious tropical species which, in this country, has only a very limited distribution in the Southwest.

Anopheles crucians has been found by King (2) to be separable into three distinct species based on larval differences and habitats.

This knowledge, at present chiefly of academic interest, may be of economic importance in connection with future developments in malaria epidemiology.

What of our other anophelines, particularly *quadrimaculatus*, *punctipennis* and *walkeri?* These are considered to be homogeneous species, but few, if any critical studies of variations in form and habits have been made throughout their range. Information especially is desirable in the case of our principal malaria vector, *A. quadrimaculatus*. Critical studies should be made to determine if it has variants in form and habits in different latitudes. An answer to this question might well explain many epidemiological puzzles and result in a considerable saving in malaria control work.

All of our anophelines have been proven capable of developing malaria parasites under laboratory conditions. Information on their susceptibility to infection and their role in transmission under natural conditions, however, is scant. In discussing this subject in "The Symposium on Human Malaria," General Simmons (3) closes his remarks on nearly every species with the statement that further work is necessary before a decision can be made relative to its importance in malaria transmission in nature. This lack of information is due, no doubt, to the fact that the collection, dissection and examination of wild-caught specimens is not only tedious but a time consuming process. Large numbers must be examined and data carefully evaluated in order to provide a basis for reliable conclusions. We, of course, are reasonably certain that our most important vectors are *quadrimaculatus* in the southeastern part of the country and *freeborni* in the west and that a potential malaria hazard exists when either of these species is present in significant numbers. Also, because of its importance as a transmitter in other parts of its range, we assume that *albimanus* is important in the lower Rio Grande Valley. Little or nothing is at hand, however, to substantiate this assumption. Some authorities are satisfied that *punctipennis, crucians, walkeri, franciscanus* and *atropos* do not transmit the disease under natural conditions and usually defend this stand by stating that these species do not have the necessary man-mosquito relationship and consequently are innocuous. Nevertheless there are other epidemiologists who maintain that these species cannot be dismissed as unimportant without further critical study.

In this connection I might state that a large scale study of the blood feeding habits of our common anophelines is now being conducted at the Carter Memorial Laboratory of the U. S. Public Health Service at Savannah, Georgia, by precipitin tests. These studies to date have not borne out the opinion that *punctipennis* and *crucians* rarely feed on man. A preliminary analysis of early season

records shows that of approximately 9,000 *quadrimaculatus* examined, 4.2% had fed on man while 3.9% of 1550 *crucians* and 3.0% of 1300 *punctipennis* likewise had had human blood meals. These data when complete for the season will be submitted to further analyses to evaluate factors such as place of collection and availability of human blood before definite conclusions are drawn. It should be mentioned in presenting these data that practically all the collections were from outbuildings, culverts, hollow trees and the like, very few were from inside human habitations. House collections undoubtedly would raise materially the percentage of *quadrimaculatus* feeding on man, since it is known to frequent houses to a greater extent than do the other species considered. However, the fact remains that *crucians* and *punctipennis* were found to feed regularly on humans. The proponents of the idea that these mosquitoes are "innocuous" might well counter that these figures simply show that at this rate for human blood meals transmission is mathematically impossible. By the same token they would insist with considerable justification that if the examinations were made of all engorged mosquitoes collected in occupied dwellings that the numbers of the "innocuous" species taken would be negligible and the percentage of "quads" feeding on human blood would be found to be of a magnitude sufficient to insure transmission. The only way to answer these arguments is by investigational work and it would seem that such is long overdue.

At the present time there is considerable discussion concerning the susceptibility of our local *Anopheles* to infection by the exotic strains of malaria with which some of our returning troops and prisoners-of-war are infected. Laboratory studies show that these strains will readily cause our commonly accepted malaria vectors to become infective. It would seem likely that factors affecting malaria transmission by these anophelines will operate irrespective of the type of parasite with which they may become infected and that only those species which normally transmit malaria in this country will be concerned. However, whether this will be the case or not deserves painstaking inquiry.

We know that it is rarely possible to eradicate an established insect pest, but we also know that with carefully supervised work it is often possible to reduce the abundance of such a species to inconsequential numbers. This brings up another point; that is, what are dangerous densities of a malaria vector? It is obvious that this will vary greatly depending on many factors, chief of which are the habits of the local anophelines which affect their efficiency as vectors and the economic status and habits of the human population. The problem is a complex one, and informa-

tion to guide our thinking on the importance of various anopheline densities in creating potential malaria hazards is greatly needed. The importance of density determinations was emphasized recently by Dr. L. L. Williams, Jr. (4) in a discussion of conditions causing outbreaks of malaria in non-endemic areas. Dr. Williams stated that outside the endemic foci of the south, the human carrier was dangerous only where the density of the mosquito vector had risen suddenly and materially as a result of the creation of new or enlarged water impoundments, the re-establishment of old ones or the clogging of natural drainage systems. He concludes that "this focuses our attention sharply on the mosquito and we should keep it there."

The measurement of mosquito populations in itself presents an interesting problem and accurate measurements are not only of importance in forming the epidemiological picture but in providing a means of determining the efficiency of anopheline control measures. As is well known to most of this group, the commonly used methods of obtaining indexes of adult anopheline abundance are by counting resting adults in their diurnal shelters, the use of animal bait traps and to a lesser extent the use of light traps and the making of biting collections. In the United States the habits of our important anophelines of spending the daytime in accessible shelters makes the use of these the most practical for index purposes. This is not the case with many tropical species for which special traps must be used. Natural resting places, of course, vary greatly and do not furnish data on abundance which are comparable for various projects. Artificial resting shelters of uniform size might be preferable. To date, however, although the microclimatic preferences of the various species have been studied superficially, a great deal of additional work to determine attractiveness will be necessary before an artificial resting place is devised by the use of which reliable comparative data can be obtained. Animal bait traps have not been employed to any extent in collecting *Anopheles* in this country although several types have been devised and are used routinely in obtaining indexes to the abundance of trophical species whose diurnal shelters either are unknown or are unsuitable for such purposes.

A stimulating development along this line is the work of Eyles (5) in devising a method of measuring the absolute mosquito population of an area. It consists essentially in collecting, marking and liberating large numbers of mosquitoes and then determining the proportion of marked individuals in subsequent catches. The absolute population is computed on the basis that the number of recaptures should bear the same relation to the total collections

made as the total marked specimens liberated bears to the total population. While the routine use of such an involved method may not be indicated, it is believed that it might be used to advantage in a number of areas to determine the reliability of our common methods of estimating population densities.

The significance of seasonal and climatic conditions, habits of over-wintering, pre-hibernation flights, and time and direction of nocturnal activity, are some of the factors to be considered in measuring adult *Anopheles* abundance about which much more information is needed.

Knowledge of flight habits of anophelines is of particular importance in control work for it governs to a large extent the size of the control program necessary. The many factors which may influence distance of flight of a species, such as availability of blood meals, terrain, size of breeding areas and prevailing winds, all are subject to such variation in different localities that it is necessary to evaluate conditions in each case before specific information on flight can be given. We know from practical experience that the effective flight range of most species of *Anopheles* mosquitoes is comparatively short. In the case of *quadrimaculatus*, flights to considerable distances have been recorded. The percentages of individuals recovered at long range have been small and they usually are believed to be of less consequence in producing important densities at a distance from breeding areas than are the mosquitoes which inadvertently escape from nearby waters which are supposed to be under effective control. This conclusion, however, may be questioned. With some species such as *A. freeborni* in California the control problem is greatly complicated by migratory prehibernation flights which carry malaria far beyond the normal flight range of the species and the possibility of such an occurrence with *quadrimaculatus* should not be overlooked.

The ecology of anopheline larvae and the bionomics of larval development have received considerable attention from investigators. We know that a given species of *Anopheles* will breed in certain situations but not in others which appear to be identical. So far the exact physical, chemical of biological factors causing this condition have not been found although it is true that certain ecological relationships have been established in which we are able to anticipate with some degree of accuracy the presence and breeding intensity of some of our *Anopheles* species. Biological means of control may exist and if they can be discovered, their application would be highly desirable from many aspects. Such methods might well be cheap and of wide application. Exhaustive studies of the ecological factors influencing oviposition and larval development in aquatic

situations therefore should be made and all leads thoroughly investigated to determine their practical application.

Accurate means of quantatively appraising the producivity of breeding areas also are needed. It is not only important to know the densities of the various larval instars but to know how many adults are produced. In some water areas mature larvae or pupae rarely are found although early instars are abundant—the so-called "incomplete breeding places." The development of a method of breeding place evaluation which takes the production factor into account is highly desirable.

The problems I have discussed by no means complete the list but are some of those which have presented themselves in connection with the prosecution of our practical malaria control work in the United States during the past three years. Among the reasons for drawing attention to these problems at this time are two which I should like to mention here. First of all, the number of men trained in the techniques of malaria investigation and control is at an all time peak. The majority of these men are now in the various services. Upon their release, many of them will be interested in continuing in health work and the time is most opportune, therefore, for health agencies to make plans for securing the services of some of these men. Secondly, although the impetus given to medical entomology by war-time problems undoubtedly will result in an increased amount of productive research on disease carrying insects by the Federal, State and other agencies already established in this field, we should not overlook the possibilities of interesting other qualified organizations in this line of endeavor. Among others there is one such group of agencies to which attention should be called. I refer to the entomological research services of our State colleges and experiment stations. These were established, of course, primarily for the investigation of agricultural insect problems, and in the past, very few of them have taken a sufficient interest in insects of medical importance to lead to significant research accomplishments. Now however many of them are keenly interested. This interest should be fostered by health authorities and encouragement and guidance freely given. Their participation in this field would materially increase contributions to medical entomology, and from such of these agencies as are located in the South, malaria control workers could expect added assistance in the solution of their problems.

This discussion has been concerned only with the need for entomological work in malaria control which is, of course, only one phase of the problem. Malaria control constitutes a large and complex field of endeavor wherein the physician, the engineer, the

parasitologist, the educator and the entomologist all have specific but nevertheless interrelated functions to perform. And in closing I want to emphasize that it will be only through concerted efforts by representatives of all these disciplines that the goal of our work, the eradication of malaria from our country, will be achieved.

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ERRATUM

Apparently because of the loss of a line of type when the number was prepared for printing, an important error occurred in the article by Kruse', Hess and Metcalf, Airplane Dusting for the Control of *Anopheles quadrimaculatus* on Impounded Waters, Vol. III, 208; 1944. Since the error concerned specifications for Paris green, the corrected specifications are reprinted below with the missing line set in italics:

> The Paris green must be of a fineness such that approximately 100% will pass a 200 mesh screen and approximately 85% pass as 325 mesh screen. It must contain approximately 55% arsenious oxide with no more than 3½% being soluble in water (all percentages by weight). The Paris green must be lethal to anopheline larvae when applied in natural breeding areas and shall weigh not *less than 60 pounds per cubic foot. Shipment must be made in tight* metal or fiber drums containing 100 pounds of Paris green. Drums shall not exceed in size 15" diameter by 18" high.

A few reprints of the paper were distributed without correction before the error was discovered, but corrections have been made on all reprints distributed subsequent to January 25, 1945.

SUPPRESSIVE TREATMENT OF MALARIA IN MILITARY FORCES*

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Suppressive treatment of malaria by continued administration of small doses of such drugs as quinine and atabrine has been an established procedure for a long time. The fact that neither drug will prevent mosquito-borne infection has been well recognized. However, either quinine or atabrine taken regularly in proper doses usually suppresses the development of symptoms and postpones illness which otherwise would be incapacitating at perhaps an inopportune time. Suppressive treatment, therefore, serves a useful purpose in military forces to maintain the effectiveness of troops which must operate in malarious territory where full protection against mosquitoes can not be given.

With the extension of our fighting fronts into some of the world's worst malaria zones it became necessary that large numbers of troops receive suppressive treatment. Tremendous experience has been gained since the start of the war on the use of drugs for this purpose. Because of limitation of the quinine supply, atabrine has been almost exclusively the drug employed. This enforced choice of atabrine for military use has not in any way been a handicap. In fact, it has turned out to be an advantage. Atabrine has proved much more effective than quinine for suppression of malaria and, in general, is better tolerated and preferred by troops.

A great deal has been learned since the start of the war regarding the use of atabrine for suppressive treatment. Based on rather limited previous experience, the first dosage used was 0.2 gram given on two non-successive days each week (total 0.4 gram per week). In hyperendemic regions it was soon evident that this amount was not sufficient to protect all troops. The dosage in such areas was increased to 0.6 gram per week, and more recently the administration of 0.7 gram per week, one 0.1 gram tablet daily, has become the recommended routine procedure. Many thousands of men have taken atabrine in these doses for periods longer than a year. Experience to date has given no evidence of toxic effects from such long-continued use of the drug.

Civilian and military investigations have shown that the concentration of atabrine in the plasma is the best indicator of the

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therapeutic and suppressive activity of the drug. Also, important information concerning the relationship between oral dosage of atabrine and the resultant plasma concentration has been gained. When daily doses are administered, about 50 per cent of the eventual level is attained after one week.

Subsequently, the plasma concentration increases at a rate of 50 per cent per week. As a result of this slow build-up, the maximal level attainable on a given dosage is not reached until after four to six weeks. This level varies considerably among a group of men taking the same amounts of drug. It would appear, however, that practically all individuals attain a plasma concentration sufficient to suppress symptoms when 0.7 gram per week is given.

The plasma concentration at which "break-through" malaria infections occur has been measured in the field. As would be expected, the concentration required for suppression varies in different individuals and probably also from time to time in the same individual, depending upon physiological, immunological, and other factors. There is some evidence that a higher plasma concentration of atabrine is required to suppress *falciparum* malaria than is necessary for *vivax* infections. Also, relapses appear to be more easily suppressed than primary attacks. Apparently less drug is required when some immunity has developed as a result of previous attacks.

A most important experience gained since the start of the war is the demonstration of the effectiveness of atabrine in preventing the development of *falciparum* malaria. When atabrine is taken in doses of 0.6 or 0.7 gram per week during and for several weeks following exposure to *falciparum* infection, appearance of symptoms is consistently prevented not only during suppressive treatment but also after medication is discontinued. Suppressive doses of atabrine apparently act as curative doses in this type of malaria. In this respect atabrine is far superior to quinine. As a result of the extensive use of atabrine for suppressive treatment, *falciparum* malaria has been much less of a problem in the military forces than was anticipated at the start of the war. In order to cure *falciparum* infections, it is now recommended that administration of atabrine be continued for at least four weeks after the last exposure to malaria.

Although atabrine is highly effective in suppressing *vivax* malaria, few if any infections are cured and clinical symptoms regularly appear after the drug is stopped. In the majority of persons the delayed primary attack is experienced within three or four weeks, but in some instances the period of latency may be extended for as long as ten to twelve months. Relapses of *vivax* malaria experienced after the cessation of suppressive medication constitute a major portion of the Army's malaria problem. In units heavily

seeded with *vivax* malaria, experience has shown that it may be necessary to continue suppressive treatment in order to maintain military effectiveness even though no further exposure to infection occurs. Otherwise, relapses may be so numerous as to prevent further active service of the unit.

Thus far, no evidence has been obtained that long continued suppressive use of atabrine will mitigate in any way the subsequent course of *vivax* infection after medication is stopped. Conditions prevailing in certain of the oversea theaters have made it necessary that large numbers of troops continue to take atabrine for periods longer than a year. It is an important question whether this amount of medication will have any favorable influence on the number or frequency of subsequent relapses. If so, the present problem of chronic relapsing *vivax* malaria may be materially reduced. A long-time follow-up observation of a large number of individuals will be necessary in order to obtain authoritative information on this question. In the meantime, we can hope for the best.

Early in the war the possibility that long continued administration of atabrine might produce drug resistant strains of plasmodia was frequently suggested. No evidence has appeared to support this hypothesis. Clinical attacks respond promptly to therapeutic doses of atabrine irrespective of previous suppressive treatment.

Many practical considerations arise in the administration of suppressive drugs to troops. When suppressive treatment with atabrine is first instituted, it is not uncommon for symptoms of intolerance to appear after one or more of the first few doses. These reactions may consist of nausea and vomiting, or occasionally, abdominal cramps and diarrhea. They are never serious and soon disappear if the drug is continued. True intolerance to atabrine has rarely been observed.

Insuring that prescribed doses of atabrine are actually taken is an important consideration in the field. The procedure by which this is accomplished is known as atabrine discipline. A check of the roster and careful observation of each man while swallowing the pill is necessary to make certain that the drug is taken regularly. Supervision is difficult during combat operations and in situations where men are detached from their units. Perfect atabrine discipline is a goal to be strived for but one which is seldom attained under field conditions. The amount of malaria appearing in a unit which is taking suppressive treatment is a direct measure of its atabrine discipline. Few cases occur when discipline is perfect.

The effectiveness of atabrine in suppressing symptoms conceals the rate at which malaria is being acquired. Apparent freedom from malaria may lead to neglect of antimosquito measures.

Consequently, it must be emphasized that when risk of infection is sufficiently great to warrant suppressive treatment it is all the more important that other preventive measures be employed.

In summary, suppressive treatment with atabrine in proper doses is a highly effective measure to prevent sickness from malaria among troops exposed in hyperendemic areas or among those already heavily seeded with infection. As far as is known, its continued use for this purpose is not harmful. It permits military operations in highly malarious territory which otherwise would not be possible without excessive disease casualties. From a practical standpoint *falciparum* malaria ceases to be a problem if atabrine is regularly and properly taken. However, *vivax* malaria is not prevented by suppressive drugs and eventually will cause incapacitation after medication is discontinued. Use of atabrine for suppressive treatment has been a great help to military forces but it must not be regarded as a solution to the malaria problem.

THE INHIBITORY EFFECT OF PYRIDOXINE ON THE ACTIVITY OF QUININE AND ATABRINE AGAINST AVIAN MALARIA*

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The fact that para-amino benzoic acid, a substance known to be necessary for the optimal growth of certain bacteria, inhibits the activity of sulfonamides supports the hypothesis first proposed by Woods[1] that the sulfonamides act by competing with para-amino benzoic acid or a compound of similar structive for a position in the metabolism of the bacterial cell. While there is no direct evidence in the literature concerning the growth requirements of the malaria plasmodia it is a reasonable assumption that they probably need at least some of the factors shown to be required by other forms of life. For the sake of a working hypothesis on the mode of action of atabrine and quinine we have assumed that these compounds act by competition with some factor necessary for the metabolism of the malaria parasite. We are, consequently, studying the effect of the addition of large amounts of vitamins on the activity of quinine and atabrine in avian malaria. In this communication experiments are reported which demonstrate that pyridoxine in massive doses inhibits the activity of quinine and atabrine against *Plasmodium lophurae* and *Plasmodium cathemerium* infections of ducklings.

In experiments on *P. lophurae*, 50 gram Pekin ducklings were inoculated intraveneously with 10,000,000 parasitized erythrocytes. In the studies on *P. cathemerium* ducks of the same size and species were used but the intavenous inoculation was 25,000,000 parasitized cells. In all cases the whole blood of infected birds was diluted in physiological saline to such an extent that the inoculating dose would be 0.2 cc. per 50 grams of bird. Blood smears were made at suitable intervals, stained with Giemsa, and the number of parasitized erythrocvtes per 10,000 erythrocytes was determined.

The birds were allowed to feed at will on a special chick starting mash, which presumably was adequately supplied with the growth factors required by the duck.

In all experiments, the quinine sulfate or atabrine hydrochloride was administered in aqueous solution into the crops of the birds by tube once daily beginning on the day of inoculation. Pyridoxine hydrochloride, also in aqueous solution, was administered either into the crops or given subcutaneously. Whenever both

*This paper was presented at a meeting of the joint session of the National Malaria Society and the American Society of Tropical Medicine, St. Louis, Missouri, 15 November 1944.

1. Woods, D. D., Brit. Jour. Expt. Path., 21:74 - 90, 1940.

pyridoxine and the antimalarial were given into the crops there was an interval of at least twenty minutes between the administration of each agent.

Massive pyridoxine doses of 500 mg./kgm. by mouth or 200 mg./kgm. given subcutaneously were used in all experiments regardless of species of parasite. The dose of pyridoxine was chosen arbitrarily and although the exact requirement for the duckling is not known it probably represented several thousand times the amount of vitamin required by the birds for optimal growth.

Although the dose of pyridoxine remained unchanged the amounts of atabrine and quinine used were varied as the species of parasite used differ in their susceptibility to the drugs. Furthermore, graded doses of atabrine and quinine were used to study the quantitative relationship between pyridoxine and the antimalarials.

Tables I and II record the results of experiments on the effect of pyridoxine on the chemotherapeutic activity of quinine and of atabrine against *P. lophurae.* 500 mg./kgm. of pyridoxine by mouth or 200 mg./kgm. given subcutaneously completely inhibited the antimalarial effect of the doses of atabrine used. These large doses of pyridoxine also influenced the activity of quinine. The degree of inhibition produced by a unit dose of pyridoxine varied with the amount of quinine used. In an experiment (Table II) in which the effect of 200 mg./kgm. of pyridoxine given subcutaneously on 15 mg./kgm. and 10 mg./kgm. of quinine was studied, it was found that there was only slight inhibition at the higher quinine level and virtually complete inhibition at the 10 mg./kgm. dose.

The results of the experiments on *P. cathemerium* are recorded in tables III and IV. It is apparent that pyridoxine is also effective in inhibiting the action of quinine and atabrine against *P. Cathemerium.*

The fact that massive doses of pyridoxine inhibited the action of atabrine or quinine raised the question as to whether the acute toxic effects of the drugs might not be similarly influenced by the vitamin. Acute oral toxicity tests were carried out in mice comparing the toxicity of quinine in animals receiving no pyridoxine beyond that contained in the diet with that in animals given a dose of 500 mg./kgm. of pyridoxine on the same day that the quinine was given and again 24 hours later. A study of the effect of pyridoxine on the toxicity of atabrine was made in the same manner. Quinine sulfate, atabrine hydrochloride and pyridoxine hydrochloride were given to 20 gram C.F.W. white mice by stomach tube. The animals were observed for seven days. The results of these experiments are shown in table V. The acute toxicity of quinine in mice receiving large amounts of pyridoxine did not differ significantly

TABLE I

Effect of Pyridoxine on the Activity of Atabrine Against the Schizonts of *P. lophurae*

Number of Ducks	Drug	Dose mg./kgm.	Route	% of erythrocytes parasitized on the 7th day
5	Atabrine	5	p.o.	2.68
	Atabrine	5		
5	Pyridoxine	500	p.o.	48.7
5	Atabrine	4	p.o.	7.4
	Atabrine	4		
5	Pyridoxine	500	p.o.	53.9
	Atabrine	4	p.o.	
5	Pyridoxine	200	s.c.	46.5
5	Atabrine	3	p.o.	34.4
	Atabrine	3		
5	Pyridoxine	500	p.o.	33.7
	Atabrine	3	p.o.	
5	Pyridoxine	200	s.c.	50.7
5	Pyridoxine	500	p.o.	46.5
5	Pyridoxine	200	s.c.	38.9
5	Controls	——	——	47.2

TABLE II

Effect of Pyridoxine on the Activity of Quinine Against the Schizonts of *P. lophurae*

Experiment Number	Number of Ducks	Drug	Dose mg./kgm.	Route	% of erythrocytes parasitized on the 7th day
1	5	Quinine	15	p.o.	1.5
		Quinine	15		
	5	Pyridoxine	500	p.o.	33.2
	5	Pyridoxine	500	p.o.	46.5
	5	Controls	——	——	51.1
2	5	Quinine	15	p.o.	0.02
		Quinine	15	p.o.	
	5	Pyridoxine	200	s.c.	5.9
	5	Quinine	10	p.o.	0.3
		Quinine	10	p.o.	
	5	Pyridoxine	200	s.c.	39.1
	5	Pyridoxine	200	s.c.	74.2
	5	Controls	——	——	66.5

TABLE III

Effect of Pyridoxine on the Activity of Quinine Against the Schizonts of *P. cathemerium* in Ducks

Number of Ducks	Drug	Dose mg./kgm.	Route	% of erythrocytes parasitized on the 5th day
5	Quinine	60	p.o.	4.8
	Quinine	60		
	Pyridoxine	500	p.o.	5.5
5	Quinine	50	p.o.	1.6
	Quinine	50		
5	Pyridoxine	500	p.o.	29.4
5	Pyridoxine	500	p.o.	33.4
5	Controls	——	——	27.2

TABLE IV
Effect of Pyridoxine on the Activity of Atabrine Against the Schizonts of *P. cathemerium* in Ducks

Number of Ducks	Drug	Dose mg./kgm.	Route	% of erythrocytes parasitized on the 4th day
5	Atabrine	4	p.o.	2.0
	Atabrine	4		
5	Pyridoxine	500	p.o.	9.8
	Atabrine	4	p.o.	
5	Pyridoxine	200	s.c.	6.6
5	Atabrine	3	p.o.	1.0
	Atabrine	3		
5	Pyridoxine	500	p.o.	23.4
	Atabrine	3	p.o.	
5	Pyridoxine	200	s.c.	24.3
5	Atabrine	2	p.o.	17.4
	Atabrine	2		
5	Pyridoxine	500	p.o.	21.5
5	Atabrine	1	p.o.	24.2
	Atabrine	1		
5	Pyridoxine	500	p.o.	24.7
5	Pyridoxine	500	p.o.	25.7
5	Pyridoxine	200	s.c.	23.9
5	Controls	-----	-----	27.5

TABLE V
Atabrine and Pyridoxine Toxicity

Dose mg./kgm.	Number of Mice	Number of animals dead at 10 days: Atabrine	Number of animals dead at 10 days: Atabrine + Pyridoxine — 500 mg./kgm.
400	10	1	3
600	10	1	6
800	10	1	5
1000	10	3	6
1200	10	8	8

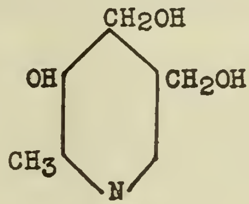
Quinine and Pyridoxine Toxicity

Dose mg/kgm.	Number of Mice	Number of animals dead at 10 days: Quinine	Number of animals dead at 10 days: Quinine + Pyridoxine — 500 mg./kgm.
600	10	0	0
1000	10	1	2
1400	10	6	3
1800	10	6	4

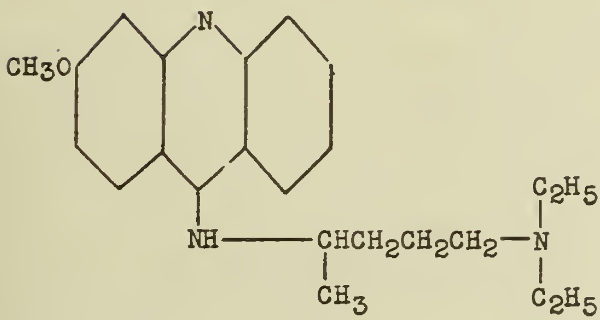
from that in the control mice. The administration of pyridoxine to mice receiving atabrine not only did not inhibit the acute toxic effect of the drug but actually seemed to increase the toxicity slightly.

The experiments reported in this communication show that massive doses of pyridoxine inhibit the activity of quinine and atabrine

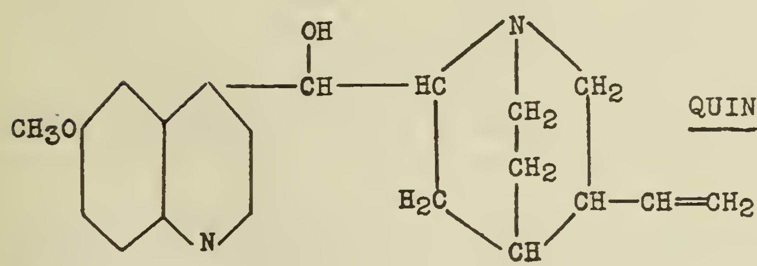
FIGURE 1



PYRIDOXINE



ATABRINE



QUININE

against two species of avian malaria in the duckling. In addition, experiments have been performed showing that pyridoxine also inhibits the activity of these drugs against another species of avian malaria in a host other than the duck but the details cannot be reported at present. In view of the results obtained with three species of avian malaria, it is probable that the mode of action of both quinine and atabrine against all species of avian malaria involves, at least to some extent, an interaction with pyridoxine or a pyridoxine like substance.

The inhibitory effect of pyridoxine may be due to one or a combination of the following mechanisms: (1) a direct chemical reaction between the drugs and the vitamin; (2) a competition between the vitamin or a derivative and the drugs or their derivatives for a position in a metabolic system of the parasite; (3) an interference with the metabolism of the drugs by the host.

The possibility that the inhibition can be explained by a direct chemical reaction of the drugs prior to absorption is unlikely since inhibition occurs even when the vitamin is given parenterally and the drugs are given by mouth.

The fact that massive doses are required and that there seems to be a quantitative relationship between the inhibiting power of a unit dose of pyridoxine and the amount of drug administered suggests that the phenomenon may be explained by a competition between the vitamin or a compound of similar structure and the drugs for a position in some enzyme system of the parasite. This explanation, while attractive, cannot be supported by any gross structural similarities between the vitamin and the drugs, as is shown in Figure 1. It is, however, possible that there is a structural relationship which, while not obvious to us, is sufficient to permit substitution in some metabolic process. If the pyridoxine antagonism is to be explained on a basis of competition, the mechanism is obscure, since we do not know where pyridoxine fits into the metabolic picture.

In vitro studies on the relationship between pyridoxine and the effect of atabrine and quinine on the malaria parasites may afford direct evidence as to whether or not the antagonism may be explained by competition.

It is conceivable that pyridoxine antagonism does not directly involve any phase of the metabolism of the parasite itself but rather may be concerned with the metabolism of the drugs in the host. Pyridoxine might, for example, interfere with some degradation process which converts the drugs into active schizonticidal agents.

Summary

Massive doses of pyridoxine inhibit the activity of minimal effective doses of quinine and atabrine against *P. lophurae* and *P.*

cathemerium infections of Pekin ducklings. The acute oral toxicity of atabrine and quinine for mice is, however, not influenced by pyridoxine.

RESOLUTION OF THE ASSOCIATION OF STATE AND TERRITORIAL HEALTH OFFICERS APPROVING EXTENDED ANTIMALARIAL ACTIVITIES

WHEREAS, malaria is still prevalent in many areas in this country causing annually many cases and numerous deaths,

AND WHEREAS, the economic losses due to malaria, while being of considerable magnitude in the highly malarious areas of the country, also have an effect on the economy of the entire United States,

AND WHEREAS, malaria cases are occurring with greater frequency in areas of the country formerly considered as nonendemic areas,

AND WHEREAS, many members of the armed forces, now, or in the future to be stationed in highly malarious areas of the world, will ultimately return to their homes many of whom are likely to be potentially chronic carriers of the tertian or vivax type of malaria,

AND WHEREAS, such members of the armed forces will be a potential source of danger as they may start an epidemic of the disease throughout the malarious sections of the United States.

AND WHEREAS, The Association of State and Territorial Health Officers realize that the defense against malaria is a defense in depth in contra-distinction to the old idea of harbor quarantine and that defense in depth involves the entire United States.

THEREFORE BE IT RESOLVED by The Association of State and Territorial Health Officers, that we approve in principle that antimalarial activities be maintained and extended to include all areas in the United States necessary for its control.

AND BE IT FURTHER RESOLVED, that the Congress of the United States be informed of the attitude of this Conference with reference to the potential danger that exists relative to a possible increase in malaria in this country following the War and that the Surgeon General of the United States Public Health Service be requested to place this matter before Congress.

FELIX J. UNDERWOOD, M.D., Chairman.
BEN F. WYMAN, M.D.,
R. H. HUTCHESON, M.D.,
Committee.

THE RELATION OF PLANTS TO MALARIA CONTROL ON IMPOUNDED WATERS WITH A SUGGESTED CLASSIFICATION

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(Received for publication 16 November 1944)

Introduction

The only important vector of malaria in the Southeastern United States, *Anopheles quadrimaculatus,* breeds in quiet, warm waters where there is an abundance of vegetation or flotage intersecting the water surface. The most important axiom concerning the ecology of this species is that "a clean water surface does not produce quads." With this long established fact in mind, the Tennessee Valley Authority initiated studies aimed at providing a more detailed knowledge of the relation of plants to malaria control on impounded waters. These studies have been chiefly ecological in nature and have involved particularly the fields of botany and limnology. Some ten years have now elapsed since the first studies were begun and during this period a considerable body of information has been accumulated. Penfound (1942) summarized the status of this information through the end of the 1940 growing season. In the four years since then much additional information has been obtained, and it is the purpose of the present paper to summarize the current status of the knowledge of the relation of plants to malaria control on the reservoirs of the Authority. Although the data were obtained almost entirely from the Tennessee Valley, it is believed that the basic principles set forth will apply to the production and control of *A. quadrimaculatus* in other parts of this country, and possibly to additional species breeding in impounded waters in this and other parts of the world.

Classification of Plants in Relation to Malaria Control

As the investigations in the Tennessee Valley have progressed, the need for developing a system for classifying plants in relation to malaria control has become increasingly evident. Such a classification is desirable in order to provide field workers with a method for determining the potential importance of plants in relation to malaria control without reference to their taxonomic status. In the spring of 1942 the first such classification was developed and during the past three seasons it has been tested in the field and some minor revisions made. It is now possible to place all plants of importance to malaria control in the Tennessee Valley in a few basic types,

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*This paper was presented at the annual meetings of the National Malaria Society in St. Louis, Missouri, 16 November 1944.

each having well-defined relationships to the biology and control of *Anopheles quadrimaculatus* on impounded waters. The criteria used in defining the types have been their anopheline production potentials and their relation to the various phases of the malaria control program such as water level management, shoreline maintenance, and the application of larvicides. In Table I is set forth the present system of classification together with the species which has been chosen as representative of each type. It will be noted that the same system has been used for subdividing the terrestrial, wetland, and emergent aquatic groups into types. Therefore, although the complete classification lists nineteen different types, these can actually be combined into the following ten basic types if we disregard the degree of adaptation to the aquatic habitat.

1. Woody
2. Erect Leafy
3. Erect Naked
4. Flexuous
5. Carpet
6. Pleuston
7. Floating Mat
8. Floating Leaf
9. Submerged
10. Microscopic

TABLE I

A Classification of Plants in Relation to Malaria Control

Types	TYPE SPECIES Common Name	Scientific Name
I. WOODY		
A. Intolerant	Red Cedar	*Juniperus virginiana*
B. Tolerant	Black Willow	*Salix nigra*
II. HERBACEOUS		
A. Terrestrial		
1. Erect		
a. Leafy	Cocklebur	*Xanthium americanum*
b. Naked	Blackberry Lily	*Belamcanda chinensis*
2. Flexuous	Crab Grass	*Digitaria sanguinalis*
3. Carpet	Lespedeza	*Lespedeza stipulacea*
B. Wetland		
1. Erect		
a. Leafy	Aster	*Aster praealtus*
b. Naked	Spikerush	*Eleocharis obtusa*
2. Flexuous	Wild Millet	*Echinochloa crus-galli*
3. Carpet	Teal Grass	*Eragrostis hypnoides*
C. Aquatic		
1. Emergent		
a. Erect		
(1) Leafy	Lizard Tail	*Saururus cernuus*
(2) Naked	Squarestem Spikerush	*Eleocharis quadrangulata*
b. Flexuous	Cut Grass	*Leersia hexandra*
c. Carpet	Water Purslane	*Ludvigia palustris*
2. Floating		
a. Pleuston	Duckweed	*Lemna minor*
b. Floating Mat	Alligator Weed	*Alternanthera philoxeroides*
c. Floating Leaf	Lotus	*Nelumbo pentapetala*
3. Submerged	Naiad	*Najas minor*
III. MICROSCOPIC	Red Water Bloom	*Euglena sanguinea*

These basic types are essentially the same as those given by Rozeboom and Hess (1944) from the original manuscript of the present paper.

There follow definitions of each of the groups included in Table 1 in accordance with the terminology used in the present paper.

Definitions

I. *Woody*—Having woody supporting tissue, typically with perennial aerial stems.
   A. *Intolerant*—Incapable of surviving in water 1 foot deep for more than one or two growing seasons.
   B. *Tolerant*—Capable of surviving in 1 foot of water for at least two growing seasons, if not completely submerged.

II. *Herbaceous*—With relatively little woody tissue; typically with annual aerial stems.
   A. *Trerrestrial*—Typically growing in relatively dry soil; usually not surviving a month's period of partial inundation during the growing season and frequently killed by a much shorter period.
   B. *Wetland*—Typically growing in soils which are saturated with water during a major portion of the growing season; usually not adversely affected by partial inundation during the growing season.
   C. *Aquatic*—Usually growing in soils covered with water during a major portion of the growing season; development inhibited by extended periods of dewatering during the growing season. (The primary subdivisions within this group are based upon the stages of a hydrosere).
      1. *Emergent*—Typically growing with some of the vegetative parts extending above the water surface.
         a. *Erect*—Standing erect with relatively firm stems and leaves.
            (1) *Leafy*—Possessing an abundance of well-defined leaves.
            (2) *Naked*—Usually lacking well-developed blades, or, if blades are present, they are linear and erect.
         b. *Flexuous*—Having stems which are relatively weak and flexuous or, if firm and erect, possessing lax leaves.
         c. *Carpet*—With relatively short shoots forming dense attached mats.
      2. *Floating*—Typically having the entire plant or some of the vegetative parts floating on the water surface.
         a. *Pleuston*—Minute plants floating free at the water surface.
         b. *Floating Mat*—Composed of relatively large plants forming a mat which floats at the water surface.
         c. *Floating Leaf*—Consisting of attached plants bearing floating leaves with relatively long flexuous petioles.
      3. *Submerged*—Typically growing with the vegetative parts largely submerged.

In Table II the more important plants in relation to malaria control in the Tennessee Valley are listed alphabetically under the types in which they have been classified. In some instances species are dimorphic; for example, lotus (*Nelumbo pentapetala*) has both floating and emergent leaves. Such species are listed under all types in which they might generally be classified, the secondary classification being indicated by enclosing the name of the species in brackets.

Contour Zonation of Plant Types

In a main river reservoir with a normal schedule of water level management there is a typical zonation of plant types at the end of the growing season (See Fig. 1). In the upper part of the zone of water level fluctuation leafy erect terrestrial species, such as goldenrods and asters, predominate. Immediately below the zone of leafy

erect terrestrials, there occurs a zone in which flexuous wetland species (such as panic grass and smartweeds) usually predominate. Agrostiform species usually occupy the upper portion of this zone and smartweeds the lower portion. The lower portion of this zone may frequently be occupied by a band of vegetation in which naked erect wetland species (such as spikerushes) predominate. In the zone immediately above the lower limit of water level recession for malaria control, wetland carpet species, (such as teal grass and water purslane) frequently predominate. It should be pointed out that, although a given plant type may predominate in a particular zone, other types are usually present and may even predominate in some areas.

TABLE II

Classification of the More Important Plants in Relation to Malaria Control in the Tennessee Valley.

Woody

*INTOLERANT**
- *Carpinus caroliniana* Walt.
- *Fagus grandifolia* Ehrh.
- *Juniperus virginiana* L.
- *Liriodendron tulipfera* L.
- *Pinus virginiana* Mill.
- *Quercus falcata* Michx.

TOLERANT
- *Acer saccharinum* L.
- *Acer rubrum var, drummondii* Sarg.
- *Berchemia scandens* Koch.
- *Brunnichia cirrhosa* Banks.
- *Campsis radicans* Seerman
- *Cephalanthus occidentalis* L.
- *Diospyros virginiana* L.
- *Forestiera acuminata* (Michx.) Poiret
- *Fraxinus pennsylvanica* Marsh. var. *lanceolata* (Borkh.) Sarg.
- *Gleditsia triacanthos* L.
- *Liquidambar styraciflua* L.
- *Nyssa aquatica* L.
- *Populus balsamifera* L.
- *Quercus lyrata* Walt.
- *Salix nigra* Marsh. (3.9)
- *Taxodium distichum* (L). Rich.

Herbaceous

TERRESTRIAL, ERECT, LEAFY
- *Ambrosia artemisiifolia* L.
- *Ambrosia trifida* L. (6.4)
- *Aster dumosus* L. (4.4)
- *Erigeron canadensis* L.
- *Eupatorium serotinum* Michx.
- *Solidago hirsutissima* Mill.
- *Verononia altissimal* Nutt.
- *Xanthium americanum* Walt. (6.8)

TERRESTRIAL, ERECT, NAKED
- *Belamcanda chinensis* (L.) DC.

TERRESTRIAL, FLEXUOUS
- *Andropogon virginicus* L. (8.2)
- *Digitaria sanguinalis* (L.) Scop. (6.7)
- *Leptochloa filiformis* (Lam.) Beauv.
- *Sorghum halepense* (L.) Pers.

TERRESTRIAL, CARPET
- *Lespedeza stipulacea* Maxim. (10.7)

WETLAND, ERECT, LEAFY
- *Ammannia coccinea* Rottb.
- *Aster praealtus* Poir. (4.4)
- *Bidens discoidea* (T.&G.) Britt.
- *Lindernia dubia* (L.) Barnhart
- *Pluchea* spp.
- *Rorippa palustris* (L.) Bess.
- *R. sessiliflora* (Nutt.) Hitch.
- *Rotala ramosior* (L.) Koehne
- *Rumex verticillatus* L.
- *Veronica peregrina* L.

(Figures in parentheses indicate production potentials in numbers of anopheline larvae per square foot. Species in brackets indicate secondary classification of dimorphic species.)

*Includes most woody species not listed in tolerant group.

WETLAND, ERECT, NAKED
- *Eleocharis engelmanni* Steud.
- *E. obtusa* (Willd.) Schult. (1.6)
- [*E. smallii* Britt.]
- *Equisetum* sp.
- *Juncus acuminatus* Michx.
- *J. diffusissimus* Buckl.
- *J. effusus* L. (1.1)

WETLAND, FLEXUOUS
- *Carex lupulina* Muhl. (3.4)
- *Cyperus erythrorhizos* Muhl.
- *C. esculentus* L.
- *C. pseudovegetus* Steud.
- *C. strigosus* L.
- *Diodia virginiana* L.
- *Echinochloa colonum* (L.) Link.
- *E. crus-galli* (L.) Beauv. (21.9)
- *Eclipta alba* (L.) Plassk.
- *Eleocharis smallii* Britt. (6.7)
- *Fimbristylis autumnalis* (L.) R.&S.
- [*Leersia hexandra* Swartz.]
- *L. lenticularis* Michx.
- *L. oryzoides* (L.) Swartz. (5.4)
- *Panicum agrostoides* Spreng. (5.1)
- *P. dichotomiflorum* Michx.
- *P. hians* Ell.
- *Paspalum distichum* L. (10.1)
- *P. fluitans* (Ell.) Kunth.
- *Polygonum lapathifolium* L.
- *P. pennsylvanicum* L.
- *P. persicaria* L.
- *Scirpus cyperinus* (L.) Kunth.
- *S. eriophorum* Michx.

WETLAND, CARPET
- *Diodia virginiana* L.
- *Eleocharis acteularis* (L.) R.&S.
- *Eragrostis hypnoides* (Lam.)B.S.P.(1.5)
- [*Ludvigia palustris* (L.) Ell.]

AQUATIC, ERECT, LEAFY
- *Armoracia aquatica* (Eat.) Wiegand
- *Echinodorus radicans* (Nutt.) Engelm. (0.7)
- *Hibiscus militaris* Cav.
- *H. moscheutos* L.
- *Hydrolea ovata* Nutt.
- *Justicia americana* (L.) Vahl.
- *Lophotocarpus calycinus* (Engelm.) J. G. Smith
- [*Nelumbo pentapetala* Walt.]
- [*Nuphar advena* Ait.]
- *Peltandra virginica* (L.) Kunth.
- *Sagittaria latifolia* Willd. (1.5)
- *Saururus cernuus* L. (3.4)

AQUATIC, ERECT, NAKED
- *Eleocharis quadrangulata* (Michx.) R.&S. (2.9)
- *Scirpus americanus* Pers.
- *S. validus* Vahl.
- *Typha latifolia* L. (0.8)
- [*Zizaniopsis miliacea* (Michx.) Doell and Aschers.]

AQUATIC, FLEXUOUS
- *Hydrolea quadrivalvis* Walt. (2.5)
- *Leersia hexandra* Swartz.
- [*L. lenticularis* Michx.]
- [*L. oryzoides* (L.) Swartz.]
- *Polygonum coccineum* Muhl.
- *P. hydropiperoides* Michx. (14.7)
- [*Proserpinaca palutris* L.]
- *Zizaniopsis miliacea* (Michx.) Doell and Aschers.

AQUATIC, CARPET
- *Eleocharis acicularis* (L). R.&S.
- *Ludvigia palustris* (L.) Ell. (7.4)

PLEUSTON (3.2)
- *Lemna cyclostasa* (Ell.) Chev.
- *L. minor* L.
- *Ricciocarpus natans* (L.) Corda.
- *Spirodela polyrhiza* (L.) Schleid.

FLOATING MAT
- *Alternanthera philoxeroides* (Mart.) Griseb. (6.2)
- [*Hydrolea quadrivalvis* Walt.]
- *Jussiaea diffusa* Forsk.
- *Myriophyllum brasiliense* Camb.
- [*Paspalum fluitans* (Ell.) Kunth.]
- [*Polygonum coccineum* Muhl.]

FLOATING LEAF
- *Brasenia schreberi* Gmel. (0)
- [*Echinodorus radicans* (Nutt.) Engelm.]
- *Nelumbo pentapetala* Walt. (1.1)
- *Nuphar advena* Ait. (0.3)
- *Nymphaea odorata* Ait. (0.2)
- [*Potamogeton diversifolius* Raf.]
- [*P. nodosus* Poiret.]
- [*P. pulcher* Tuckerm.]

SUBMERGED
- [*Armoracia aquatica* (Eat.) Wiegand]
- *Anacharis canadensis* (Michx). Planchon.
- *A. densa* (Planchon) Marie-Vict.
- *Ceratophyllum demersum* L. (3.7)
- *Chara* sp. (5.4)
- *Heteranthera dubia* (Jacq.) MacM.
- [*Ludvigia palustris* (L.) Ell.]
- [*Myriophyllum brasiliense* Camb.]
- *M. heterophyllum* Michx.
- *M. scabratum* Michx. (5.7)
- *Najas guadalupensis* (Spreng.) Morong.
- *N. minor* Allioni (5.0)
- *Nitella sp.* (20.1)
- *Potamogeton crispus* L.
- *P. diversifolius* Raf.
- *P. nodosus* Poiret
- *P. pectinatus* L.
- *P. pulcher* Tuckerm. (2.1)
- *Proserpinaca palustris* L. (5.4)
- *Ranunculus circinatus* Sibth.
- *R. flabellaris* Raf.
- *Utricularia gibba* L. (5.9)

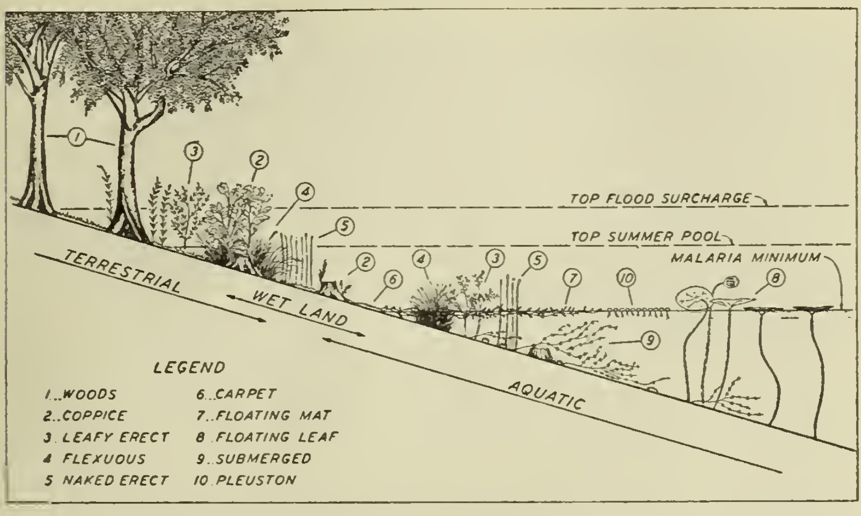

Fig. 1. General Relationship of Plant Types with Reference to Contour Distribution and Water Levels on the Shoreline of a Main River Reservoir in which Normal Water Level Management Schedules are Utilized.

If coppice is subjected to an annual "rebrushing" operation, it will normally be limited to the upper portion of the zone of water level fluctuation. However, if it is not rebrushed, coppice of water tolerant species will continue to survive in the deeper water areas beyond the zone of fluctuation for malaria control.

The typical zonational relationships of the plant types in a main river reservoir are presented diagrammatically in Fig. 1. The zonation of aquatic plants which is given in this figure represents only the interrelationships of the aquatic types, and it should be pointed out that these types actually overlap the terrestrial and wetland types. For example, floating mat species (such as alligator weed) may be rooted up to the top summer pool level, and in wet springy areas leafy erect aquatics (such as lizard tail) or naked erect aquatics (such as cattail) may occur throughout the fluctuation zone. The aquatic types which usually occur nearest to shore are the leafy, naked, and flexuous emergents and the floating mat species. The submerged aquatics usually extend from the zone of fluctuation into water several feet deep. The floating leaf types may occur from the lower part of the zone of fluctuation into water at least eight feet in depth. Although pleuston is free floating, it is generally restricted by wave action and therefore occurs mainly in association with other plant types.

Anopheline Production Potentials of Plant Types

During the summer of 1940 the Authority began using the screen dipper and strainer pan (Hess, 1941) to secure quantitative

data on the production of anopheline mosquitoes. By this method, populations of anopheline larvae are expressed as numbers per square foot of water surface. During the past five years, over 7,000 square foot samples have been taken in some 44 species of plants of importance to malaria control in the Tennessee Valley. Each species has been sampled only in pure stand with the exception of pleuston and woods; also, sampling was done only in areas in which significant numbers of larvae occurred at the time of inspection. The mean number of larvae per square foot for each of the plant species for which dipping records are available is given in Table 2. The *Anopheles quadrimaculatus* production potentials of the ten basic plant types are presented in Table III. Although attempts were made to obtain larval dipping records when conditions were near optimum, this was not always possible. The actual numbers of larvae per square foot for the various species within a given plant type therefore varied considerably, as will be observed from the standard errors given in the table. Additional dipping records might therefore change the relative positions of adjacent types in the table (such as coppice and erect leafy); however, it is believed that the actual order of the various types with reference to their anopheline production potentials is essentially similar to that given in the table. For general reference, the ten plant types may be placed in three natural groups: (1) those with *high* production potentials (flexuous, submerged, carpet, floating mat); (2) those with *medium* production, potentials (erect leafy, coppice, pleuston); and (3) those with *low* production potentials (woods, erect naked, floating leaf).

With the initiation of quantitative methods of sampling anopheline larvae, attempts were made to determine the factors responsible for the different anopheline production potentials exhibited by the different plant species. It soon became obvious that the linear extent of the intersection between plant and water surface was an important factor in this respect. This factor was termed the intersection line, and preliminary investigations were made of its relation to anopheline production during the summers of 1941 and 1942. (Hess and Hall, 1943). These studies were followed up during the summer of 1943 with more detailed observations, the results of which (Rozeboom and Hess, 1944) established the fact that in the Tennessee Valley intersection line is the dominant factor in determining the *Anopheles quadrimaculatus* production potentials of different plant species. The relative anopheline production potentials of different plant types were also shown to be in direct proportion to their relative intersection values (meters of intersection line produced per square meter of water surface), other factors remaining equal. In Fig. 2 are presented in graphic form the anopheline

production potentials of the ten plant types listed in Table III. It will be observed that those types (such as flexuous and submerged) which have the highest intersection values also have the highest production potentials and that those types which have the lowest

TABLE III

Anopheles quadrimaculatus Production Potentials of Plant Types of Importance in Relation to Malaria Control.

TYPE	Number of Species	Number of Samples	Number Larvae Per Sq. Ft. Plot Maximum	Number Larvae Per Sq. Ft. Mean*
Flexuous	11	1748	49.9	7.9±1.8
Submerged	8	473	37.0	6.7±2.0
Carpet	3	155	11.2	6.5±2.7
Floating Mat	1	680	26.0	6.2±1.9
Erect Leafy	7	1113	15.2	4.2±0.9
Coppice	3	160	19.6	3.9±1.4
Pleuston	3	28	6.0	3.2±0.6
Woods	Several	390	5.6	1.9±0.6
Erect Naked	4	438	6.2	1.6±0.5
Floating Leaf	5	2271	7.5	1.1±0.7
TOTALS	45	7456		

*Plus or minus figures are standard errors of the type means which were derived by averaging the means for the individual species comprising the type. Where type means are derived from only one species, the standard error refers to the individual dipping records for that one species.

intersection values (such as naked erect and floating leaf) also have the lowest production potentials. It should be emphasized that the production potentials indicate the capacity of the plants to "produce" mosquitoes under favorable conditions of temperature, water level, etc. For example, submerged aquatics cannot produce *Anopheles quadrimaculatus* except when they intersect the water surface.

The anopheline production potential of flotage is also governed by the amount of intersection line produced per unit of water surface area. The highest production of mosquitoes in flotage occurs where this material is moderately abundant and produces a high intersection value. Where flotage is so abundant that it completely covers the water surface, intersection line is eliminated and there is no production of larvae.

The term "anopheline production potential" as used above refers to the number of larvae per square foot which may be produced by a given plant species or plant type under favorable conditions and thus makes possible direct comparisons of the production capacities of different species or types on a unit area basis (Table III and Fig. 2). Of even greater importance is the "total production potential" which is the product of the total area colonized times the larval density (production potential). This value, therefore, expresses the production potential on a regional basis. Thus, one acre

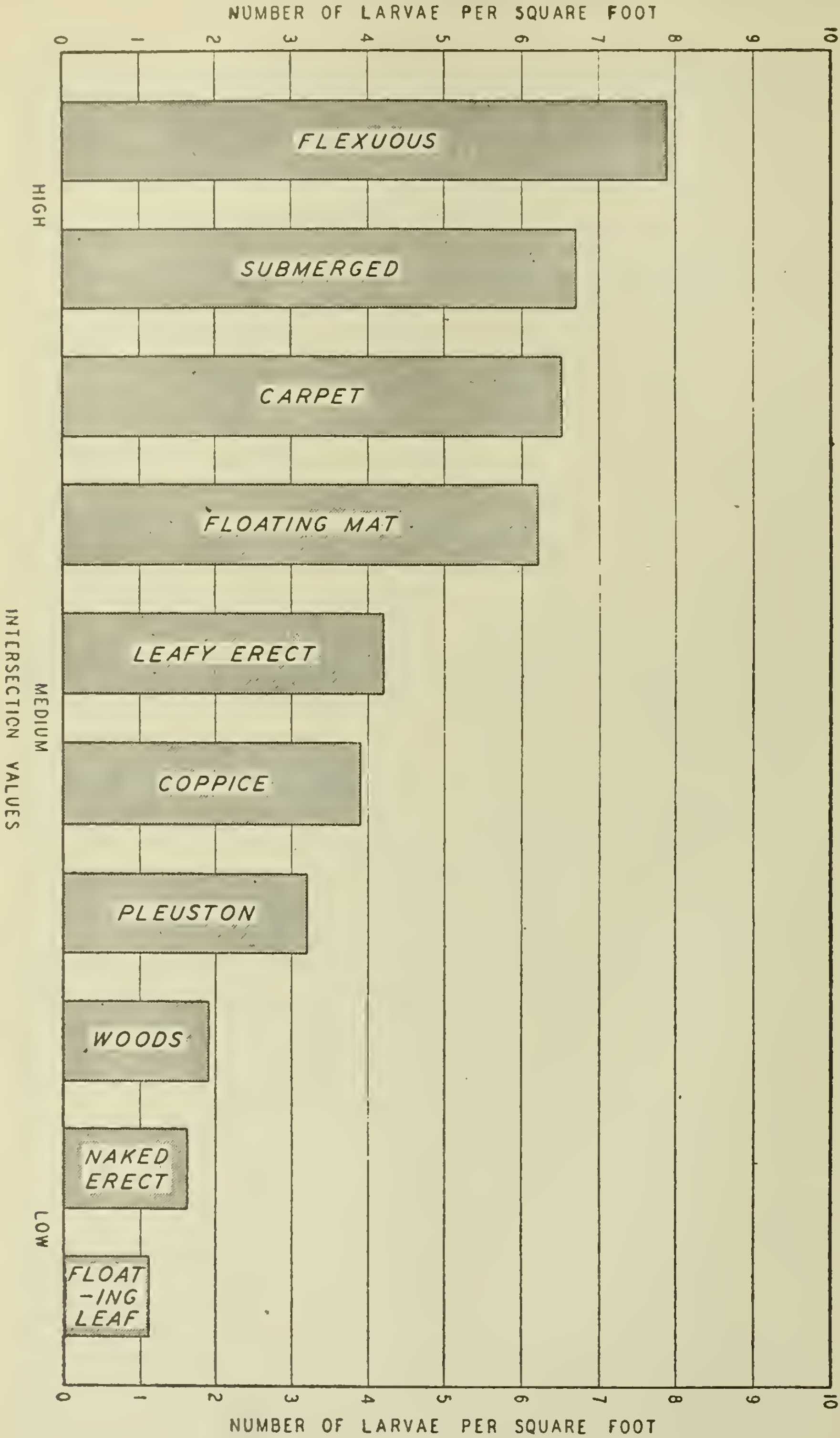

Fig 2. *Anopheles quadrimaculatus Production Potentials of Plant Types of Importance in Relation to Malaria Control. (Based on 7,316 square foot samples in 44 herbaceous species and several woody species, 1940-1944).*

of a plant species having a production potential of 10 larvae per square foot would have a total production potential of 435,600 larvae (10 larvae per sq. ft. times 43,560 sq. ft. per acre).

Some plant types having high production potentials may be relatively unimportant in a particular region because they do not colonize extensive areas and, therefore, have low total production potentials. For example, in the reservoirs of the Authority, submerged acquatics, which have high production potentials, are of little importance because they cannot survive dewatering and are, therefore, largely eliminated from the zone of fluctuation which greatly restricts their area of colonization. Also, the period during which they may intersect the water surface is usually of short duration. On the other hand the floating leaf type, which has the lowest production potential of all, is the most important type with reference to mosquito production in some of the Authority's reservoirs since it has a high colonization potential, occurs in solid stands over extensive backwater areas, and extends the anopheline breeding area beyond the zone of marginal vegetation into deep water.

Plants in which Propogation of A. quadrimaculatus Does Not Occur

Of all the plants in the reservoirs of the Tennessee Valley for which extensive dipping records are available, one species, watershield (*Brasenia schreberi*), stands out as being inimical to the production of *Anopheles quadrimaculatus*. Over 400 square foot samples have been taken in this species in the Tennessee Valley over a three-year period and only an occasional anopheline larva has been found. Observations in the vicinity of Montgomery, Alabama, indicate that a similar situation exists there. Observations by Bellamy (1940) in Georgia also indicate that watershield is not associated with the production of *A. quadrimaculatus*. Frequently high densities of anopheline larvae will be found in other plants immediately adjacent to non-breeding colonies of watershield. For example, in one instance, larvae averaged about 5 per sq. ft. in a colony of *Polygonum hydropiperoides* just a few feet from a colony of *Brasenia* in which not a single larva could be found.

Studies in the Tennessee Valley indicate a number of possible reasons why production of *A. quadrimaculatus* does not occur in *Brasenia schreberi*. This species has a clear gelatinous coating on the stems and under sides of the leaves and does not support the growth of epiphytic algae and plankters which are commonly associated with other floating leaf types such as lotus. Another possible reason for the absence of anophelines from colonies of *Brasenia* is that the water is almost invariably acid. The pH usually ranged between 6.0 and 7.0 and sometimes was as low as 5.8. This acidity is apparently due to dissolved CO_2 since the residual pH of water

in which this species was growing was always alkaline, usually ranging from 7.8 to 8.1. The chief reason for the acid reaction of the water in colonies of *Brasenia* is therefore apparently due to the fact that it takes CO_2 for photosynthesis directly from the atmosphere while at the same time completely covering the water surface and preventing photosynthesis by submerged species; thus, the carbonic acid content of the water is built up from the CO_2 given off from organic decomposition and respiration. Frequently water from colonies of submerged aquatics (which remove CO_2 directly from the water) showed a highly alkaline reaction, even though located immediately adjacent to colonies of *Brasenia* in which the water was acid; however, residual pH determinations in the two situations usually gave identical readings. Colonies of *Brasenia* usually almost completely cover the water surface and therefore exhibit very low intersection values, which might be one of the reasons why production of *A. quadrimaculatus* does not occur in this species; however, this does not explain the absence of anopheline breeding in sparse stands of *Brasenia* which have high intersection values.

Another floating leaf plant, white waterlily (*Nymphaea odorata*) has been included by Bellamy (1940) among the plants in which production of malaria mosquitoes does not generally occur; however, Bradley (1932) has reported high production in this species when growing in association with submerged aquatics. White waterlily is not common in the Authority's reservoirs but does occur in ponds in the Valley. Our limited dipping records bear out Bellamy's contention that white waterlily is not generally associated with the production of *A. quadrimaculatus*.

There has long existed a conflict of opinions as to whether malaria mosquitoes will breed in association with the duckweed, *Lemna minor*, (Matheson, 1930). This species rarely occurs in dense stands in the reservoirs of the Authority; however, dipping records obtained at Reelfoot Lake in *Lemna minor* occurring in association with *Wolffia papulifera, W. columbiana,* and *Spirodela polyrhiza* indicate that breeding in these species is directly correlated with intersection values. As many as 20 larvae per sq. ft. occurred where the plants were scattered and the intersection value high, but no production occurred where the plants formed a dense mat completely covering the water surface. These observations are in agreement with those of many other workers in this country (Bishopp, 1933 and 1934; Bradley, 1932; Howard, 1910).

Observations by Matheson and Hinman (1931) indicate that the submerged aquatic, *Chara,* inhibits the production of mosquitoes. Our observations in the Tennessee Valley indicate that high densi-

ties of *A. quadrimaculatus* are associated with *Chara,* larval counts being as high as 27 per sq. ft. This would be expected from the high intersection values exhibited by this plant. The species of *Chara* in which our observations were made have not been determined, and it is possible that different species might vary with regard to their effect upon anopheline production.

Utricularia is a genus of submerged aquatics which has received publicity as a predator of mosquito larvae (Matheson, 1930). Dipping records in the Tennessee Valley in *Utricularia gibba* indicate that, as might be expected from its high intersection values, high populations of *Anopheles quadrimaculatus* larvae occur in association with this plant. Some single square foot dips have contained as many as 25 larvae and many fourth instar larvae occurred in the samples. The small bladders of this species might be responsible for its apparent inability to reduce significantly populations of anopheline larvae. Twinn (1931) reached similar conclusions concerning small bladdered species of *Utricularia.*

Limited dipping records with parrot's feather, *Myriophyllum brasiliense,* in the Tennessee Valley indicate that production of *A. quadrimaculatus* does not occur in this species. Sufficient data are not available for any conclusive statement in this regard; however, the limited observations are in agreement with those of Bachmann (1921) who observed that *Anopheles* larvae were not found associated with this plant.

Relation of Microscopic Plants to Anopheline Production

Microscopic plants have two important relations to the production of anopheline mosquitoes: (1) they serve as a principal source of food for the larvae; and (2) they may frequently be used as biological indicators of anopheline breeding conditions. Investigations on the relation of plankton to anopheline breeding in the Tennessee Valley were made by the senior author during the summer of 1941 (Hess, 1942a). In general, the results of these studies were in agreement with those of Bradley (1932) and indicated little correlation between the kinds of microscopic plants occurring in an area and the amount of anopheline breeding; however, stations where anopheline production was heavy usually had an abundance of microscopic plants, particularly Chlorophyceae. The group which appeared to be most indicative of unfavorable conditions for anopheline production was the Euglenophyceae and of this group the genus *Euglena* appeared to be the most important. Anopheline larvae were never found where there was a heavy water bloom of *Euglena,* and this genus occurred only occasionally or rarely in situations where anopheline breeding was heavy. Such correlations did not hold for all genera within the Euglenophyceae; for example, the

genus *Phacus* was frequently common in situations where anopheline larvae were abundant. An abundance of filamentous blue-green algae (particularly *Oscillatoria*) was commonly associated with heavy water blooms of *Euglena*. Algae are able to utilize relatively complex nitrogenous compounds as their source of nitrogen, and species of *Oscillatoria* and *Euglena* are among those whose occurrence is especially influenced by the nature and amount of available nitrogenous compounds (Smith, 1933). The actual factors which limit anopheline production in situations where these algae abound may therefore result from the interaction of oxygen and nitrogen compounds as has been discussed by Senior-White (1938).

Particular attention was given to investigating the relationships of desmids to anopheline production. Frohne (1939) has given a key to pond classes in Georgia in which he uses desmid populations and hydrogen ion concentration as the principal criteria for separating favorable and unfavorable habitats for *A. quadrimaculatus* production. He divided all ponds into two classes, the "desmid-rich" (having 5 to 18 genera of desmids and a pH of 5.2 to 6.7) and the "desmid-poor" class (having 1 to 8 but usually less than 3 genera of desmids and a pH of 6.8 to 8.6). He further stated that *A. quadrimaculatus* appeared to be principally associated with waters of the desmid-poor class, being restricted or inhibited in the desmid-rich class. Our observations in the Tennessee Valley indicate that all anopheline breeding places fall within Frohne's "desmid-poor" class. Of 20 stations sampled, only one had 8 genera of desmids and all others had 5 or less. Thus, our information is in agreement with Frohne and would indicate that, in general, the waters in the Tennessee Valley are all potentially favorable breeding places for *A. quadrimaculatus*. Parallel studies on hydrogen ion concentration, however, do not agree with Frohne's key. Anopheline breeding waters in the Tennessee Valley may frequently have a pH reading as low as 6.0 and quite commonly have readings below 6.8 (Hess, 1942). No larvae of *A. quadrimaculatus* were found where the pH was below 6.3, and there was some indication that breeding was inhibited where the pH was below 6.5; however, heavy production occurred over the entire range from pH 6.5 to pH 10.0. If the water samples were first agitated in order to bring the dissolved gases to equilibrium with the atmosphere and the determination of the residual pH then made, most values were between 7.8 and 8.2 with none being below 7.7. This would indicate that acidity in the anopheline breeding waters of the Tennessee Valley is entirely due to dissolved carbon dioxide resulting from decomposition and respiration. If we substitute RpH for pH in Frohne's key, his observations are in close agreement with ours. It, therefore, seems likely

that the desmid-rich waters which he studied in Georgia were acid due to other substances than dissolved gases. Thus, our observations on hydrogen ion concentration indicate the desirability of making determinations of residual pH in studies on anopheline ecology, which is in agreement with the suggestions of Senior-White (1928).

Relation of Plant Types to Reservoir Preparation

The relation of plant types to reservoir preparation concerns chiefly the woody species. For a number of years the Authority's reservoir clearance specifications have included a provision for "low stumping" the zone of fluctuation in the major problem areas. This low stumping, in addition to facilitating post-impoundage shoreline maintenance, is of marked importance with reference to controlling coppice of water tolerant woody species such as black willow. Stumps of these species will not resprout until dewatered but may produce an abundance of coppice if exposed to the air during the full growing season. Low stumping lengthens the period during which the stumps will be submerged during the growing season and thereby results in decreased production of coppice and quicker killing of the stumps. The treatment of flush cut stumps of these water tolerant species with arboricidal oils has also been effective in limiting the production of coppice where the stumps are exposed to the air early in the growing season.

The differentiation between tolerant and intolerant types of woody plants is important in the preparation of the flood surcharge zone of a reservoir. It is frequently desirable to remove from the lower part of this zone the most intolerant species in order to prevent their being killed by inundation when the flood surcharge zone is used during the growing season and subsequently adding to the malaria control problem through the creation of drift and flotage. For this reason provisions for selective clearing in the flood surcharge zone have been included in specifications for reservoir preparation.

Coppice is of particular importance with regard to the final conditioning of the zone of fluctuation of a reservoir just prior to impoundment. Coppice of water tolerant species will continue to grow in water of considerable depths if portions of the plant protrude above the water surface; however, if this coppice is cut so that it will be continuously flooded during the major portion of the growing season, it will be either killed or its growth greatly retarded. A similar situation prevails with reference to the practice of "topping" tall coppice occurring below the proposed zone of water level fluctuation. Terrestrial plants of the erect leafy type, such as giant ragweed, are also of importance in relation to the final reconditioning operation. If these plants are not removed, the dead stems

persist over winter, collect flotage, and create a mosquito breeding problem during the initial season of impoundage.

It is frequently desirable during reservoir preparation to eliminate small colonies of undesirable aquatics (such as lotus) which would serve as colonization foci following impoundment.

Relation of Plant Types to Water Level Management for Malaria Control

During recent years water level management has assumed an increasingly important role in the malaria control program of the Tennessee Valley Authority. The present status of this measure in the Tennessee Valley has been discussed in detail by Hess and Kiker (1944). The primary objective of water level management is to provide for the reduction or elimination of intersection line at the proper time and intervals to insure effective control of anopheline breeding. The type of water level management schedule which is most applicable on any particular reservoir is a combination of all or a part of the following four phases: flood surcharge, relatively constant pool, cyclical fluctuation, and seasonal recession.

A particular phase may function primarily to control larvae or it may be directed at the plants or flotage which would produce larvae. In either case, plant types greatly influence the effectiveness of the operation. The function of the flood surcharge phase is to strand the winter's accumulation of drift and flotage before the beginning of the mosquito breeding season. This phase, therefore, is concerned chiefly with woody species and those erect leafy species which have parts which will persist through the winter months and serve as a source of flotage during the following season. Also, those species with stems which remain erect during the winter months collect flotage and prevent it from being stranded during the use of the flood surcharge. Seeds, particularly of wetland and terrestrial species, are another important source of flotage.

The relatively constant pool phase of water level management for malaria control is directed not at the mosquitoes but at the plants which would produce them. In general, all woody species and terrestrial and wetland herbs require dewatering before the seeds will germinate or overwintering parts will resprout. The constant pool phase is, therefore, intended to delay the initial growth of these species until the middle of the season and to decrease the extent to which they will invade the zone of water level fluctuation. The constant pool phase may also serve actually to control woody species and perennial terrestrials and wetland species by keeping the overwintering parts submerged for a sufficient portion of the growing season to kill them.

Plant types are of paramount importance with reference to cyclical fluctuation which is the third phase of water level management for malaria control. This phase has several functions: the drawdown eliminates existing populations of anopheline larvae and inhibits the growth of submerged aquatics, and the return to the original elevation retards the invasion of marginal vegetation. Control of anopheline larvae by cyclical fluctuation is relatively ineffective in flotage and the floating type plants (floating leaf, floating mat, and pleuston) since these types merely rise and fall with the changing water elevations, thus maintaining their intersection values and the associated populations of mosquito larvae.

Cyclical fluctuation of limited amplitude is also ineffective in the flexuous type since the flexuous portions of these plants may rise and fall to a limited extent with changing water elevations, thus maintaining a favorable habitat for the mosquito population which they harbor; most effective larval control is therefore achieved when this type is completely dewatered at the low point of the cycle.

The coppice and erect leafy types produce leaves only on those portions of the plants which are at or above the water surface. Since intersection values in these types are created principally by leaves, lowering the water elevation down around the naked stems greatly reduces the intersection line and results in effective control of anopheline larvae.

As indicated in Fig. 2, the carpet type plants have high intersection values and therefore high production potentials for *A. quadrimaculatus;* however, because of their low height, the band of production is very narrow. Under conditions of normal water level management, plants of the carpet type do not invade the water to any marked extent and cyclical fluctuation of the usual amplitude of one foot is usually effective in controlling anopheline breeding in this type.

The naked erect type has relatively low intersection values, and production of mosquitoes in this type is further limited through the creation of a mechanical barrier to the ovipositing adult mosquitoes (Rozeboom and Hess, 1944). Anopheline production in this type is generally not significant and can be controlled by cyclical fluctuation of sufficient amplitude to dewater the plants at the low point of the cycle.

In areas colonized by submerged aquatics, cyclical fluctuation may actually create more favorable conditions for anopheline production if the plants intersect the water surface at the low point of the drawdown; however, under normal operation schedules, the water is not held down for a sufficient period of time to result in any significant mosquito production. If submerged aquatics are

already intersecting the water surface, reduction of the intersection values can be achieved by increasing the water levels and resubmerging the plants; however, experience in the Tennessee Valley indicates that situations where this type of fluctuation could be effectively used are very limited.

If a reservoir has been properly prepared, there will be no woods (large trees) remaining in the flooded portion of the reservoir during the mosquito breeding season. However, if such a situation does occur, cyclical fluctuation will be effective if the woods are dewatered at the low point of the cycle.

The fourth phase of water level management (seasonal recession) is used to insure that the water level will be below the main band of vegetation at the low point of cyclical fluctuation. This phase has the same general relationships to the various plant types as the recession portion of cyclical fluctuation. Seasonal recession is very effective in limiting the development of submerged aquatics in reservoirs since plants of this type are readily attenuated or destroyed by dewatering. Seasonal recession results in the gradual lakeward extension of terrestrial and wetland species which require dewatering in order to germinate, resprout, or maintain significant growth. It is, therefore, desirable to limit seasonal recession to the minimum amount necessary for adequate mosquito control in order to keep the zone of invasion of these plant types as narrow as possible, and thus reduce the cost of the annual shoreline conditioning operation.

In addition to the relation of plant types to the normal schedules of water level management for malaria control, certain important relationships exist with reference to abnormal schedules of water level management. For example, summer flooding for even relatively short periods may kill many of the terrestrial types (such as cocklebur). Even aquatics (such as lotus) may be killed or greatly inhibited by complete inundation during the growing season. Furthermore, the aquatic types may be either killed or their growth inhibited by extended periods of dewatering during the growing season.

A detailed account of the water level relationships of plants of importance to malaria control will be given in a separate paper (Hall and Hess, 1944).

Relation of Plant Types to Shoreline Maintenance

Shoreline maintenance is one of the most important phases of the Authority's malaria control program and is intimately associated with water level management. The principal operations of shoreline maintenance are rebrushing (removal of coppice), mechanical removal of rough (dead aerial portions of herbs), area burning, and

aquatic growth control. Which of these operations will be used in a particular situation is determined primarily by the plant types occurring there. Rebrushing is directed toward the removal of the woody species and, after the first year or two of impoundment, involves almost entirely the water tolerant type. The above ground parts of these plants live through the winter in a dormant condition and begin growth in the early spring if exposed to the air; however, if these parts are kept submerged, they will remain dormant. Therefore, the removal of coppice in the zone of water level fluctuation has a double function: first, to get rid of material which would catch flotage and create intersection line during the following breeding season; and second, to hold water tolerant species in the dormant condition until later in the growing season, thus greatly decreasing their total amount of growth. Also, many of the water tolerant stumps will be killed if the coppice has been removed and they are kept submerged during a major portion of the growing season. With these facts in mind, it is apparent that rebrushing of the water tolerant woody species is one of the most important operations in shoreline maintenance.

Mechanical removal of rough either by hand or by machine is directed primarily at the leafy erect terrestrials and to a lesser extent to the leafy erect wetland species. All of the leafy erect terrestrials which are of importance to malaria control have stiff erect stems which persist through the winter months and often through the entire following season. If these dead stems are not removed, they will collect flotage and create favorable breeding conditions for *A. quadrimaculatus* during the following breeding season. The same is true of a considerable number of leafy erect wetland species although some of these have only a small amount of mechanical supporting tissue and therefore break down and disappear during the winter months. In general, the leafy erect terrestrial and wetland species will not carry a running fire and therefore they must be either removed by hand or mowed and burned.

The use of area burning is limited almost entirely to areas where flexuous terrestrial or wetland species are dominant. The flexuous types include principally the grasses and smartweeds, and under favorable weather conditions the rough of these plants may be effectively removed with running fires after the first heavy killing frost. Where coppice or seedlings of water tolerant woody species are associated with the flexuous types, the use of running fires is also very effective in controlling them. In general, flexuous types break down during the winter months and do not prevent the strandage of flotage the following spring as do the leafy erect species. However, the flexuous species do produce some flotage if not re-

moved, and therefore the elimination of the overwintering rough of these species through the use of running fires is desirable wherever applicable.

In the Tennessee Valley, erect naked species occur chiefly in the wetland group, most of them belonging to the genera *Eleocharis* and *Juncus*. These species are of minor importance and usually do not require any shoreline conditioning. Carpet-forming species are also of minor importance and do not involve the use of any shoreline maintenance operations.

The relationships of the aquatic group to shoreline maintenance operations are quite different from those of the terrestrial and wetland groups. Leafy erect aquatics usually contain much less supporting tissue than the terrestrial and wetland species and often the above ground portions are entirely dissipated during the winter months. For example, lizard tail is one of the commonest species in the Valley and plays an important role in mosquito production but it dies down and disappears completely during the winter months. One aquatic of the naked erect type (cattail, *Typha latifolia*) and one of the flexuous type (saw grass, *Zizaniopsis miliacea*) may require special control measures. Cattail may be effectively controlled either by cutting and flooding or dewatering and cutting. Cutting and flooding has proved to be the most practical means of control for saw grass. As in the case with terrestrial and wetland species, aquatic carpet species are of no importance with reference to shoreline maintenance. The floating aquatics (except pleuston) are of paramount importance and often require the use of special control measures. The floating mat type contains only two important species in the Tennessee Valley, alligator weed (*Alternanthera philoxeroides*) and water primrose (*Jussiaea diffusa*). A number of years of experience with alligator weed have indicated that this species may be most effectively controlled under the conditions existing in the Tennessee Valley by drawing the water down during the growing season and applying herbicides to the dewatered plants. Ordinary kerosene has proved to be an effective herbicide for this operation. Mechanical removal of small isolated patches during the growing season may also be desirable in keeping this species under control. Although water primrose occurs in ponds in the Tennessee Valley, it has not yet been found in any of the Authority's reservoirs. If this species does become established in some of the reservoirs, its anopheline production potentials and methods of control would probably be similar to alligator weed. Water primrose is much less tolerant to long periods of dewatering than alligator weed and this fact might be of importance in its control.

The floating leaf aquatics also require special control measures. The only two species which are of major importance in the Tennessee Valley are lotus (*Nelumbo pentapetala*) and cowlily (*Nuphar advena*). Of these, lotus is by far the more important. The most effective means of controlling these species has been found to be recurrent cutting beneath the water surface during the growing season. The use of an aquatic mowing machine, such as the Hockney underwater weed cutter, adds to the facility and economy of carrying out this operation.

The occurrence of well-developed colonies of pleuston in the reservoirs of the Tennessee Valley is limited to a few small spring-fed areas, and this type is of no importance with reference to shoreline maintenance. Submerged aquatics are, in general, effectively controlled through the use of water level management and do not therefore affect the shoreline maintenance operations.

The use of marginal grazing as a biological means of growth control on the Authority's reservoirs is encouraged wherever it fits into the over-all land use program. Grazing is effective against coppice, most terrestrial and wetland species, and some aquatics; however, there are some leafy erect species against which grazing is not effective. Notable among these are *Pluchea* sp., *Eupatorium serotinum*, *Hibiscus moscheutos*, *Vernonia altissima*, *Saururus cernuus*, and *Helenium tenuifolium*.

Relation of Plant Types to the Application of Larvicides

The most important factor governing the relation of plant types to the application of larvicides is the amount of cover above the water surface. It is, therefore, the coppice, erect leafy, and flexuous types which have the greatest bearing on the effective application of larvicides for the control of *Anopheles quadrimaculatus*.

In the Authority's malaria control program the use of airplanes has proved to be the most economical and flexible means of applying mosquito larvicides. and the present outlook is for even greater emphasis on the use of airplane rather than boat or hand application. Kruse et al (1944) have recently summarized the Authority's experience with the use of airplanes for applying larvicides. Quantitative studies on the airplane distribution of Paris green larvicides indicate that plants decrease the amount of larvicide reaching the water and therefore diminish the effectiveness of the operation in direct proportion to the per cent cover of their above water portions. Thus, for equal effectiveness the rate of application must be doubled if the above water cover is increased by 50 per cent (e.g. 10 to 60 per cent).

In case of flooded woods, the airplane application of larvicides is complicated by the additional factor of the height of the forest

canopy above the water surface. Recent experience with the airplane application of DDT thermal aerosols indicates that effective control of *A. quadrimaculatus* breeding in flooded woods can be obtained at reasonable rates of application. Little detailed information is available on the effectiveness of Paris green applied by airplane through a forest canopy since the reservoirs of the Authority are all cleared prior to impoundage. Limited tests indicate that effective penetration of the margins of wooded areas with Paris green can be achieved by airplane application since the material actually "rolls" in through the trees rather than settling down through the canopy.

Plant types such as submerged, floating leaf, and floating mat, in which the cover is mostly at or beneath the water surface, offer little interference to the effective application of larvicides by airplane. In some instances, the floating mat and floating leaf types may also become leafy erect and they then have the same relations to the application of larvicides as the normal leafy erect types. Because of the relation of emergent plant cover to the effectiveness of airplane application of larvicides, it is frequently desirable to time the application with the low point of cyclical fluctuation in order that the water may be largely withdrawn from the leafy erect and flexuous types when the larvicide is applied.

Although airplanes play the dominant role in the application of larvicides on the Authority's reservoirs, there is still some application of oil larvicides by hand and by powered boat units. Hand and boat larviciding is generally restricted to relatively abrupt shorelines having a narrow band of vegetation or to small areas inaccessible by airplane. One of the distinct advantages in applying larvicidal oils with power units rather than by hand is that sufficient pressure may be used to drive the oil into vegetation of the floating mat or leafy erect type and thus achieve much more effective control. This is of special importance in controlling breeding in any herbaceous growth with a dense aerial cover.

Summary of Relation of Plant Types to Malaria Control

The factors which govern the practical importance of plant types in relation to malaria control are those which influence the economy and effectiveness of operations directed towards the control of the malaria vector. Thus, the relative importance of a given type is not determined just by its anopheline production potential, but also by the extent of its colonization and the difficulty and expense involved in achieving control of the plant or of the mosquito breeding associated with it. With this in mind, an over-all evaluation has been made of the ten plant types discussed in this paper with reference to their potential importance to the control of *Ano-*

pheles quadrimaculatus on impounded waters, and the information is summarized in Table IV.

It will be noted that the floating leaf type (in the Tennessee Valley, mainly lotus and cowlily) is ranked first in importance even though it has the lowest production potential of all types. This is due chiefly to the fact that lotus and cowlily have very high colonization potentials and may extend the anopheline breeding area into deep water. Under normal water level management schedules, the marginal band of vegetation will usually be restricted to the upper foot or two of contour; however, lotus will commonly grow in water as much as 8 ft. deep. It may, therefore, change vast areas of open water into favorable breeding grounds for *A. quadrimaculatus*, thus tremendously increasing the total anopheline production potential of a reservoir. In addition, water level management is ineffective in controlling anopheline breeding in the floating leaf types and, therefore, costly plant control or permanent shoreline improvement measures are necessary in order to eliminate the problem.

Ranking close to the floating leaf type in degree of importance is the floating mat type (alligator weed and water primrose). This type is placed second chiefly because its colonization potential is not as high as the floating leaf type. The species in the Tennessee Valley which belong to this type become rooted only in the shallow water near shore, and the amount to which they can extend the anopheline breeding area out over deep water is limited to one season's growth. Therefore, although this type has a high colonization potential, it is not nearly as high as the floating leaf type. The water hyacinth (*Eichhornia crassipes*) forms unattached floating mats which may develop independently of the shoreline. This species, therefore, has a very high colonization potential and would rank of equal or even greater importance than the floating leaf type. Although water hyacinth has been found in reservoir areas in the Tennessee Valley, it is believed that it is probably unable to survive the low temperatures which occur at this latitude during an average winter.

Water tolerant coppice is ranked third in importance. Although this type has a high colonization potential, anopheline production in it may be controlled reasonably well by means of cyclical fluctuation, and the coppice itself can largely be brought under control through the use of desirable shoreline maintenance and water level management practices.

The flexuous type is accorded fourth place and is ranked above the erect leafy type because it has a higher total anopheline production potential and because this production is more difficult to control by water level management than it is in the erect leafy type.

TABLE IV

Relative Potential Importance of Plant Types in Relation to the Control of *Anopheles quadrimaculatus* on Impounded Waters. (Listed in order of importance.)

TYPE	ANOPHELINE PRODUCTION POTENTIAL	RESERVOIR COLONIZATION POTENTIAL	EFFECTIVENESS OF WATER LEVEL MANAGEMENT		SHORELINE MAINTENANCE		APPLICATION OF LARVACIDES	
			For Plant Control	For Mosquito Control	Cost	Effectivenes	Cost	Effectiveness
1. Floating Leaf	Low	Very High	Low	Low	High	High	Low	Medium
2. Floating Mat	High	High	Low	Low	High	High	High	Medium
3. Coppice (Tolcrant)	Medium	High	Medium	Medium	High	Medium	High to Low	Medium
4. Flexuous	High	Medium	High to Low	Medium	Low	High to Medium	High	Medium to Low
5. Erect Leafy	Medium	Medium	High to Low	High	Medium	High to Medium	High	Medium to Low
6. Erect Naked	Low	Medium	Low	High	Low	Medium to Low	Low	High
7. Submerged	High	Low	High	Medium	None		Low	High
8. Carpet	High	Low	High	High	None		Low	High
9. Pleuston	Medium	Low	High	Low	None		Low	High

The erect naked type is placed sixth in importance. Although this type is generally of little concern because of its low anopheline production potentials, some species, such as cattail, have rather high colonization potentials in the zone of fluctuation and may frequently require the application of special growth control measures.

The submerged aquatic type is ranked seventh even though it has one of the highest anopheline production potentials. It is given this low rank of importance chiefly because of its inability to survive dewatering which greatly limits its colonization potential under normal water level management schedules. It, also, requires no shoreline maintenance operations. The submerged type may be of greater importance on reservoirs where the seasonal recession of water level is less than 3 feet.

The carpet type is placed next to last in importance. Although it has a high anopheline production potential, its total production potential is low because it colonizes only limited areas and provides a very narrow band of potential mosquito production because of its low height. It is of no importance in relation to shoreline maintenance operations.

The last type, pleuston, is of no concern with reference to malaria control on impounded waters in the Tennessee Valley because, under normal water level management schedules, it is limited to small areas where water levels are maintained by springs or seepage and even in these areas it has a very low anopheline production potential.

It should be emphasized that the relative importance assigned to the different plant types in Table 4 is potential rather than actual. For example, if a given reservoir lacks the floating leaf and floating mat types, then coppice would rank first in actual importance. However, the potential hazard of the floating leaf and floating mat types remains in view of the possibility of their being introduced into the reservoir.

Current Status of Plant Types in the Reservoirs of the Authority

Some comment should be made on the relative importance of the different types in the Authority's reservoirs at the present time. Although the floating leaf and floating mat types occur in the Valley, they have been eradicated from some reservoir areas and in the remaining ones in which they occur, they are being constantly reduced through special control measures and permanent shoreline improvement. On a Valley-wide basis, water tolerant coppice, therefore, ranks first in importance at the present time. This type is, however, being constantly reduced, particularly in the lower portion of the zones of fluctuation through the application of arboricides, shoreline conditioning, and favorable water level management. It,

therefore, seems possible that within the next few years this type will become limited to the upper part of the zones of fluctuation and may then be of less actual importance than the flexuous and erect leafy types. Under present conditions in the reservoirs of the Tennessee Valley, the general order of acutal importance of all types except the first two is as listed in Table IV.

Cooperative studies in the Tennessee Valley have established the principle that the production of desirable wildlife food plants is encouraged by setting plant succession back to its early stages. In general, the malaria control shoreline maintenance procedures, therefore, constitute favorable management practices with reference to the production of waterfowl food plants. These procedures result in an increase of the desirable plant species such as smartweeds, nut grasses, wild millets, and cut grasses, and a decrease in undesirable types such as coppice, floating leaf, and floating mat. The mutual interests of wildlife conservation and malaria control have recently been discussed in detail by Wiebe and Hess (1944).

Acknowledgements

All of the members of the Biology Staff of the Health and Safety Department have participated in gathering field data during the several years in which the information submitted in this paper was accumulated. Mr. C. C. Kiker and other members of the Engineering Staff have provided valuable field data and criticism, particularly with reference to the observations on shoreline maintenance and water level management. The early studies on relation of plant species to production of *Anopheles quadrimaculatus* were also participated in by the Biological Readjustment Division of the Forestry Relations Department and by representatives of the U. S. Fish and Wildlife Service and U. S. Public Health Service, and the continued cooperation and advice of these groups have been of real value in carrying out the studies. Special thanks are due to Professor William T. Penfound of Tulane University for his enthusiastic support and advice during the course of the studies. He has been associated with the botanical phases of the Authority's malaria control program since the spring of 1937 and his participation in the research program is responsible in a large measure for the progress which has been made. Valuable assistance has also been given by Professor W. C. Muenscher of Cornell University with reference to the ecological classification of plant types and the identification of various species. Finally, appreciation is expressed to Mr. C. W. Kruse for assistance in the preparation of illustrations.

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NATIONAL MALARIA SOCIETY

Meeting Conjointly with the Southern Medical Association

Minutes—1944

Officers

Honorary President—Dr. Frederick L. Hoffman, San Diego, Calif.
President—Mr. G. H. Bradley Atlanta, Georgia
President-Elect—Mr. H. A. Johnson, Memphis, Tennessee
Vice-President—Dr. Stanley B. Freeborn, Atlanta, Georgia
Secretary-Treasurer—Dr. Mark F. Boyd, Tallahassee, Florida

Tuesday, November 14, 9:00 *a.m.*

The National Malaria Society convened for its twenty-seventh annual meeting in Room 3B of the Municipal Auditorium, St. Louis, Missouri, on November 14, 1944.

The initial scientific session, which was held jointly with the Sanitary Engineers' and Sanitation Officers' Section, Southern Branch, American Public Health Association, was presided over by Mr. G. H. Bradley, the Society's President, with Mr. R. E. Dorer, Chairman of the above section, participating.

A program consisting of eleven contributed papers, most of which were illustrated by lantern slides, was presented. Subsequently there was a brief recess for the retirement of visitors, after which the Society reconvened in business session.

The minutes of the 1943 meeting held in Cincinnati, Ohio, were approved as published in Volume III, No. 2, of the Society's Journal. The President announced the appointment of the temporary nominating and auditing committees.

In the absence of Colonel Charles F. Craig, Editor of the Journal, his report was read by the secretary, accepted with thanks, and ordered filed.

The secretary reported that from the 1943 roster of 293 honorary and active members, one, Lt. Wm. Gordon, U.S.N., had been lost in action, one had resigned, two had been transferred to honorary membership, and four had been dropped for delinquency in dues. One hundred and twenty-seven new members had been gained by election. The current roster shows twenty-one honorary and three hundred and ninety-four active members, of whom three

hundred and twenty-six were in good standing as of the date of the report.

The condition of the treasury was reported to be as follows:

Balance of November 10, 1943	$1,626.07
Receipts from delinquent, current and advance dues, subscriptions and advertising	3,862.10
	$5,488.17
Expenditures before paying for Vol. III, No. 4 of the Journal	1,847.73
Balance	$3,640.44

The report also listed assets of $3,715.44 and liabilities of $538.50, leaving a net balance of $3,176.94, which is largely in the publication fund.

The secretary informed the society that circumstances would not permit his continued acceptance of the honor of this office for more than one further term.

The report of the secretary-treasurer was referred to the consideration of the auditing committee.

Reports were submitted from the committees on Medical Research, by Dr. Martin D. Young, Chairman; Entomology, by Mr. J. A. Mulrennan, Chairman; Engineering, by Dr. C. M. White, Chairman; Statistics, by Dr. E. C. Faust, Chairman, and Epidemiology, by Dr. R. B. Watson, Chairman. These were accepted with thanks and ordered submitted to the publications committee. Similar disposition was ordered of a report from the Health and Safety Department of the Tennessee Valley Authority dealing with the malaria control program in the Kentucky reservoir, which was submitted by Mr. F. E. Gartrell.

On proceeding to the consideration of new business, an extensive discussion originated relating to the policies of the present Editorial Board of the Society's Journal. A motion was adopted directing the president to appoint a special committee to survey the situation and render a report at the adjourned business session. The president announced the appointment of Mr. Louva G. Lenert, Chairman, Dr. Trawick Stubbs and Mr. Melvin H. Goodwin to the committee.

The session adjourned at 12:45 p.m.

Wednesday, November 15, 9:00 *a.m.*

The program of this date was presented at a joint meeting of the National Malaria Society and of the American Society of Tropical Medicine, in room 3A of the Municipal Auditorium, over which Mr. G. H. Bradley and Dr. Wilbur A. Sawyer, presidents of the respective societies, jointly presided.

The program consisted of eleven scientific papers, most of which were illustrated by lantern slides.

The meeting adjourned at 12:12 p.m.

Thursday, November 16, 9:00 *a.m.*

The session was opened by the President in room 3A of the Municipal Auditorium. A program of twelve scientific papers, including the presidential address, was presented, most of which were illustrated by lantern slides. At the close of the session there was a brief recess for the retirement of visitors, and the Society then reconvened in business session.

The auditing committee reported by Major S. C. Dews that they had checked the accounts of the secretary-treasurer and found them to be in order, and moved their acceptance, which motion carried. They also introduced a motion authorizing an honorarium of $100.00 to be allowed the secretary's assistant, which was adopted. The committee introduced a further motion requiring that arrangements be effected by the treasurer, with approval of the president, for his bonding at the expense of the Society, in such amount as may protect the Society's funds, which was adopted. The committee also recommended that the by-laws be suitably amended by the provision of a joint custodianship for the society's funds, so that they would not become frozen in the event of the disability or death of the treasurer. This matter was referred to the attention of the incoming resolutions committee.

A motion was adopted endorsing the recommendations in the report of the committee on Medical Research. Of particular significance are: (a) the recommendation that members observe in their writings the standardized malaria terminology proposed by the Malaria Commission of the League of Nations; and (b) emphasizing the need for further long range research on the fundamental biology of the malaria parasites.

Dr. Herbert Clark, on behalf of the resolution committee, presented the following series of resolutions, all of which were on motion adopted, viz.:

a) Expressing the appreciation and thanks of the Society to Colonel Charles F. Craig for his successful editorship of the Journal;
b) Expressing the appreciation and thanks of the Society to Dr. Mark F. Boyd for his services in the office of secretary-treasurer;
c) Expressing the Society's appreciation of the value of the service rendered by those members who are in the armed forces; and
d) Of sympathy and condolence to Mrs. Wm. M. Gordon, for the loss in action of her husband, a lieutenant in the medical corps of the Navy, and a member of the Society.

On behalf of the same committee, Doctor Clark introduced a series of proposed amendments to the constitution and by-laws, relating in a broad way to the allocation of part of the annual dues paid by each member to a subscription to the Journal, and to the duties of the Editorial Board.

After some discussion of these topics, a motion was adopted suspending other consideration until after consideration of and action on the report of the special committee headed by Mr. Lenert. This report approved of the above mentioned amendments proposed by the resolutions committee, and further recommended that:

a) the name of Dr. Robert B. Watson be recommended by the Society to the incoming president for appointment to the Editorial Board, with the further recommendation to the Editorial Board that they designate Doctor Watson as editor;

b) owing to the absence of Dr. Lloyd E. Rozeboom from the country, and of his consequent inability to serve on the Editorial Board, he be requested to relinquish this post, in order that the incoming president may fill the vacancy by the *ad interim* appointment of some members who can serve actively;

c) all members of the Editorial Board adhere closely to their duties and responsibilities as defined in the constitution and by-laws; and

d) the board be empowered to effect modifications in the amounts charged members for extra pages, tables and cuts, at their discretion, within the limits of the funds available for the Journal.

After some discussions, a motion adopting these recommendations was carried.

On returning to the discussion of the constitutional amendments, the following proposals were accepted on motion for final consideration at the next annual meeting, viz.:

Resolved that paragraph (b) of Section 3 of the Constitution be amended by the omission of the last sentence reading "However, the member so dropped may be reinstated by the Secretary-Treasurer upon payment by the member of all delinquent dues," and the substitution therefor of the following sentences:

On payment of the annual dues, two ($2.00) dollars thereof shall be set aside by the treasurer as a subscription to the Society's Journal during the corresponding year for the member so paying. The issues of the current volume of the Journal shall not be distributed to members prior to the payment of their dues for the current year, nor to members in arrears or delinquent. Members

who apply for re-instatement by payment of deliquent dues shall be required to pay $1.00 (one dollar) for each year of their delinquency, but they will not be furnished with copies of the Society's Journal for the period of their delinquency. They may secure available back issues of the Journal at *pro rata* cost.

Be it further resolved that the first sentence of the second paragraph of section 10 of the constitution be amended by the substitution of the word "Journal" for "proceedings" and the omission of the second, third and fourth sentences, and that when so altered this paragraph shall become the third paragraph in this section.

Be it still further resolved that a new second paragraph be inserted in section 10 of the constitution to read as follows:

There is hereby established the Journal of the National Malaria Society, the editorial direction of which shall be managed by the Editorial Board as provided in the by-laws. As soon as financially practicable, the said board shall cause the Journal to be issued as a quarterly during any calendar year, and that each volume thereof shall correspond to the calendar year. Subscriptions from members or non-members shall be accepted for complete volumes only.

The following changes to the by-laws were on motion duly adopted, viz.:

Be it resolved that the second paragraph of section 8 of the by-laws be amended by the omission of that part of the first sentence reading "which have not been selected for inclusion in the malaria symposium appearing in the Southern Medical Journal."

Be it further resolved that: the two dollar subscription to the Journal annually paid by the members of the Society, and all other revenues derived from subscriptions paid by non-members, advertising and the sale of extra copies or back issues, shall be kept by the treasurer in a special publication fund, which may only be drawn upon to pay the publication and distribution costs of the Journal.

Be it still further resolved that: the Editorial Board shall have full authority to formulate and administer the editorial program for the conduct of the Journal, and that the secretary-treasurer shall be business manager thereof. Prior to publication of the initial issue of any volume of the Journal, the editorial board shall recommend to the president the sum which in their opinion shall be allocated from the publication fund for the publication of the volume in question. If this recommendation is approved by the president, this amount together with revenues subsequently derived from advertising insertions in the component issues of the volume, may be drawn upon to defray the publication costs.

A motion from the floor was adopted, empowering the incoming president to appoint a special committee to consider the adequacy of the present constitution and by-laws, and submit a report with recommendations at the next annual meeting.

A recommendation from the resolutions committee, submitted by Doctor Clark, that consideration be given to the creation of a board of councilors empowered to transact the routine business of the Society, subject to annual ratification by the Society, was on motion referred to the committee on constitutional changes for consideration and report.

A motion was adopted instructing the Editorial Board to increase the advertising rates in the Journal.

A motion was adopted directing the secretary to express the thanks of the Society to the management of the Southern Medical Association and the St. Louis Medical Society for their hospitality and the facilities enjoyed.

The nominating committee, in presenting their report through Doctor R. B. Watson, urged that the incoming president appoint his nominating committee at as early a date as practicable, in order that they may give adequate consideration to the selection of a new secretary-treasurer for 1946. The committee then submitted the following slate, viz.:

Honorary President—Mr. J. A. LePrince, Memphis, Tennessee

President—Mr. H. A. Johnson, Memphis, Tennessee

President-Elect—Dr. Mark F. Boyd, Tallahassee, Florida

Vice-President—Dr. Clay G. Huff, Chicago, Illinois

Secretary-Treasurer—Dr. Mark F. Boyd, Tallahassee, Florida

There being no nominations from the floor, a motion was adopted directing the secretary to cast the unanimous ballot of the Society for the nominees.

There being no further business, the meeting adjourned *sine die* at 2:30 p.m.

Approved:

G. H. Bradley, President

National Malaria Society

MALARIA CONTROL IN THE UNITED STATES*

CHARLES M. WHITE
U. S. Public Health Service, MCWA, Raleigh, North Carolina
MARK D. HOLLIS
U. S. Public Health Service, MCWA, Atlanta, Georgia
WILLIAM A. LEGWEN
U. S. Public Health Service, MCWA, Macon, Georgia
JOHN E. TAYLOR
U. S. Public Health Service, MCWA, Little Rock, Arkansas
JOHN L. PORTER
U. S. Public Health Service, MCWA, New Orleans, Louisiana

Regular Malaria Control Programs

Malaria Control Programs, with the exception of MCWA, have become casualties of the war. A few are still in operation though badly crippled. Some are dead, while others, though alive, are completely missing in action. This condition was brought about by the absorption of many engineers and other personnel into the Armed Forces and the MCWA Program, while others have been lured away to higher paying positions in industry.

No malaria control activities of an engineering nature, other than MCWA, are being conducted by the following states, with the exception of those in cooperation with other organizations, such as the TVA, hydroelectric companies, the Fish and Wild Life Service, the Agricultural Adjustment Agency, and others:

Florida
Illinois
Indiana
Kentucky
Maryland
Mississippi
Missouri
Oklahoma
Tennessee

In the following states at least one engineer or entomologist is employed who devotes his time to working through county and local health officers, assisting in local problems, acting as adviser on mosquito control programs, and promoting the formation of mosquito abatement through the organization of municipal and other local programs:

Alabama
Arkansas
California
Georgia
Louisiana
North Carolina
South Carolina
Texas
Virginia

During the year impounded water regulations were adopted by the states of Arkansas and Missouri.

In Arkansas the Bureau of Sanitary Engineering, in cooperation with the University of Arkansas and other public health agencies,

*Report of the Committee on Engineering to the National Malaria Society, St. Louis, Missouri, 16 November 1944.

is carrying on a study at the Rice Experiment Station of methods to reduce both anopheline and culicine breeding which occurs in rice fields as a result of the irrigation practice which is necessary in rice culture. These studies confirm previous findings that larvicidal Paris green has no appreciable effect on the yield of rice or rice straw.

In Virginia the State Legislature has made a special appropriation to provide funds for surveys which may be necessary because of the return of military personnel infected with malaria.

In North Carolina special maps are being prepared in areas proven to be highly malarious by blood slide surveys or other means to present an accurate picture of the problem and facilitate control operations.

The activities of the Agricultural Adjustment Agency in promoting and subsidizing the construction of ponds for watering stock, fish, irrigation, recreation, and other purposes, are viewed with alarm, as these ponds will undoubtedly increase the future malaria problem in rural area. While the agency requires that property owners agree to comply with existing state health laws, the vast number of potential malaria mosquito-breeding areas being created practically precludes future routine inspection and law enforcement by qualified personnel.

Malaria Control in War Areas

Malaria Control in War Areas, being an emergency program, operates on the hypothesis that cheap, temporary measures, when effective, shall be used thus saving money, labor, and critical equipment needed in the war effort. Larvicides in general have been found cheaper in most cases than other control measures. There are, however, special conditions which make other methods necessary, such as drainage, filling, diking, ditch flushing, ditch lining, and the destruction of adult mosquitoes.

Larviciding

In some of the states bordering the Gulf of Mexico larvicides were applied throughout the year. The length of the larviciding season diminishes in the Northern States to as little as two months.

Number 2 fuel oil is the larvicide most commonly used on the program in the United States. Paris green was also applied in large quantities and organic larvicides used to a lesser extent.

While oil larviciding was applied principally by hand, the use of power equipment greatly increased during the year, there now being over fifty such units in operation.

In areas where oiling was impractical or ineffective, Paris green was used extensively. Most of the Paris green was applied by hand, but power dusters and airplanes were also utilized.

On impoundments where the application of oil or Paris green was found to be objectionable, the original or a modified New Jersey larvicide was found to be effective. Phenol larvicide, which has the objective characteristic of being toxic to animal and vegetable life, was used in a few areas.

Extensive field tests are being made with DDT. This material shows spectacular results against adult mosquitoes, but its value as a larvicide is still in the experimental stage.

The following tabulation shows the extent, cost, and rates for the larvicides applied on the program:

Item	Cost Per Acre For Applying	Man Hours Per Acre	Acres Treated	Material Per Acre
Larvicide Oil				
(a) by hand	$5.25	8.07	80,705	18.9 gal.
(b) by power unit	1.55	—		
Paris green				
(a) by hand	1.85	1.7		
(b) by power unit	1.28	—	187,799	1.3 lbs.
(c) by airplane	1.12	—		

Cost per hour for the plane and power on airplane dusting was $75.00. About two hundred acres per hour can be dusted by a small plane.

Filling

Filling is the most desirable form of malaria control, since it permanently eliminates mosquito-breeding places. During the year approximately eighty thousand cubic yards of fill were placed at an average cost of 42 cents per cubic yard.

Drainage

Drainage was untaken on MCWA projects where larviciding could not effectively be accomplished or when the cost could be amortized within five years by the savings on larvicidal cost. Sixty-three major drainage projects were in operation during the year. A large number of hand ditches were dug, dynamite ditching extensively utilized, some dragline work performed, and a small amount of subsurface drainage installed. Most of the small ditches were cut by hand labor at an average cost of $1.10 per cubic yard. Over one million cubic yards of material were removed in completing one thousand fifty-nine miles of hand ditches.

Where soil conditions were favorable for propagation dynamiting, it was found that dynamite ditching was entirely satisfactory and more rapid, as well as more economical. A crew of three men can blast about one thousand feet during one day after the right-of-way is cleared. This type of ditching costs around 25 cents per cubic yard.

Twenty-six thousand eight hundred four lineal feet of subsurface drains were installed.

Approximately sixty thousand lineal feet of permanent ditch lining were installed during the year. Cost figures for this work are not available.

The cooperation of the MCWA Headquarters Office and the various State Health Departments in gathering material for this report is gratefully acknowledged.

REPORT OF THE EDITOR OF THE JOURNAL OF THE NATIONAL MALARIA SOCIETY, 1944

The Journal of the National Malaria Society will enter its fourth year in January 1945. This year it has been published as a quarterly, and practically all of the papers presented at the last annual meeting of the Society have been published as well as others. It is not too much to hope that in time our Journal will appear as a bimonthly provided sufficient material is contributed and it receives the same support that it has been receiving during the past year. The financial condition of the Journal is most satisfactory, thanks to the labors of our Secretary, and will be reported upon by him in his annual report to the Society.

While at the beginning it was impossible to publish papers other than those presented at the annual meeting because of lack of space, the quarterly publication of the Journal has made it possible to publish papers by contributors throughout the year, and such papers are solicited from both members and others interested in malariology. That our Journal is regarded as a valuable one by the profession of the world is evidenced by the frequent abstracts of its papers which have appeared in domestic and foreign medical and scientific journals during the past year. This furnishes the best of all evidence of the high character and scientific value of the papers we have been so fortunate as to have been able to publish in the Journal.

The Editor desires to express his sincere thanks to our Secretary for his constant advice and assistance, without which it would have been impossible to achieve the success that we may rightly claim for our Journal.

Charles F. Craig
Colonel, U. S. Army, Retired
Editor

THE IMPORTATION OF EXOTIC ANOPHELINES INTO THE UNITED STATES*

JOHN A. MULRENNAN
Florida State Board of Health, Jacksonville
MELVIN GOODWIN
U. S. Public Health Service, MCWA, Atlanta, Georgia
R. C. SHANNON
International Health Division, Rockefeller Foundation, Port-of-Spain, Trinidad

The present emergency has greatly increased the possibility of exotic species of insects gaining ingress and becoming established in North America. This can be partially demonstrated by the fact that alien anophelines have been collected in two localities in Florida, with the inference on aircraft importation, since the specimens were collected adjacent to air fields.

In the process of routine anopheline inspections by Mr. Ernest V. Welch, entomologist, U.S.P.H.S., on August 19, 1943, in the area around Morrison Field, West Palm Beach, a female *Anopheles* (*Nyssorhynchus*) species was found under a concrete bridge about one mile from the runways on the air base. The mosquito was collected dead, entangled in a spider web, and since the hind tarsi were missing it was impossible to make a species determination.

During a careful search of the entire area surrounding the air field no more tropical anophelines were encountered, nor have any been collected up to the present time.

On May 16, 1944, a single specimen fourth instar *Anopheles albimanus* larvae was collected by Pfc. Ernest Erb while dipping in a canal L-9a, running north and south through the eastern section of the Boca Raton Army Air Field. The canal is approximately 300 yards from the runway. Pfc. Erb took 125 dips in the canal and collected two larvae, one of which was identified as *Anopheles albimanus* Wiedeman and the other as *Anopheles quadrimaculatus* Say.

The area in and outside of the reservation was carefully combed for resting imagines and a total of 9,555 dips was made for larvae in canals and other bodies of water but no other *A. albimanus* were encountered.

From a report prepared by Captain Ernest R. Tinkham, Sn. C. (1), Boca Baton Army Air Field, it was revealed that on April 28th, a plane from Boca Raton Field made a three day flight to San Juan, Puerto Rico, returning on May 1st, 1944, after clearing through Morrison Field. There is no record of fumigation on the return trip, which strongly suggests that a female *A. albimanus*, coming in from Puerto Rico, oviposited at Boca Raton sometime

*Report of the Committee on Entomology to the National Malaria Society, St. Louis, Missouri, 16 November 1944.

after the plane's arrival. The fourth instar larva of *A. albimanus* was collected on May 16th, 1944, which would closely approximate the time interval required.

Considering the adult specimen collected at Morrison Field to have been an *albimanus,* these are the first two records of this species collected in Florida under natural conditions since the discovery of *Anopheles albimanus* at Key West, Florida, on July 29, 1904, by Dr. George N. MacDonell. During the period from July 29 to August 20, Dr. MacDonell was reported by King (2) to have collected a total of 131 specimens (2 males and 129 females) taken from stables and residences within a single city block. The breeding place was never discovered, and it was suggested by Dr. MacDonell that the captured adults were the progeny of a single female, possibly brought by vessel from Vera Cruz, Mexico.

In a personal communication from Dr. Calvin B. Spencer, Officer-in-Charge, U. S. Quarantine Station, Miami, Florida, the following information was obtained regarding the different species of anophelines collected from airplanes in the process of quarantine inspections at Miami during the period January 1 to October 1, 1944.

For this period, a total of thirty-six anophelines was collected from aircraft arriving at Miami from foreign ports. All specimens were dead when recovered, and the species collected by months are as follows: January, one *A. crucians* and one *A. grabhamii;* February, one *A. walkeri* and one *Anopheles* species; March, three *A. crucians* and one *A. grabhamii* and one *A.* (*Nyssorhynchus*) species; April, two *A. crucians* and one *Anopheles* species; May, one *A. albimanus* and one *A. crucians;* June, nine *A. albimanus;* July, one *A. albimanus,* one *A. grabhamii,* one *A.* (*Nyssorhynchus*) species and two *Anopheles* species; August, one *A. albimanus,* one *A. pharoensis,* and one *A.* (*Nyssorhycnhus*) species; September, five *A. crucians.*

It would appear from these observations that without constant vigilance there is a possibility that foreign species of anophelines may enter and become established in the United States. In this connection it seems indicated that stringent measures of control should be worked out between the military, state, and Federal quarantine service and applied to disinsectization of all aircraft before departure for this country from a foreign port. Regardless of how effective the inspection and quarantine service is at the ports of entry, there is always the possibility that insects may escape before fumigation.

The logical solution of this problem appears to be one in which the emphasis is placed on the insecticiding of aircraft at the port of debarkation, and a second application and inspection at the port of entry. Under such an arrangement there would be a double

assurance of protection that would lessen the possibility of injurious insects of all types entering the United States.

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RECENT ADVANCES IN THE EPIDEMIOLOGY OF MALARIA*

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The Committee on Epidemiology had planned this year to make its report in the form of a symposium on the epidemiology of malaria in the various war theaters. Restrictions on the publication of information on malaria of military significance made this plan impossible of fulfillment; consequently, the report follows precedent in summarizing the more recent available literature on epidemiology. However, an attempt has been made to emphasize information which appears to have a bearing on war time and post war malaria problems.

It now seems evident that in spite of every reasonable precaution on the part of the Army and Navy, many members of the armed forces will return to civilian life with malaria infections. This circumstance is due, of course, fundamentally to the fact that the war is being and will be fought in some of the most malarious situations in the world. The few published papers by naval and military personnel give some data of significance regarding the circumstances attending the infection of personnel in the current war theaters. Other papers permit reasonable speculations on the malaria problems to be encountered.

It appears that the entire Pacific war area is highly malarious, with the exception of a few oceanic islands, and some of these may become malarious if a vector is introduced. In the Southwest Pacific the vector appears to be *Anopheles punctulatus* (typicus) (Taylor 1943), but in the South Pacific, *Anopheles moluccensis* is reported to be the only vector (Butler 1943). In view of the relative lack of systematic entomological work before the war, it may be that considerable confusion may still exist concerning taxo-

*Report of the Committee on Epidemiology to the National Malaria Society, St. Louis, Missouri, 16 November 1944.

nomic and bionomic characteristics of the *punctulatus* group. In any case, certain generalizations seem warranted: vectors of the group propagate prolifically in almost any collection of still water that is not densely shaded, even brackish water; they are shy but bite man readily and evidently are efficient vectors, although no publicized record of gland infection rates has been found. Butler reports infection rates of 2,600 cases per 1,000 per year before control measures became effective. Simpson, *et al* (1943) found that of 3,417 individuals with malaria, about 1 per cent had quartan infections, 38 per cent *vivax*, and 26 per cent *falciparum*. In 35 per cent the parasite species was not identified. Presumably many, perhaps most, of these infections were with *falciparum*.

While there have been no recent papers, the older literature on the subject indicates that the Philippines are quite malarious. Formerly at least transmission was largely through *A. minimus phillipinensis*, a stream breeder in contradistinction to the *punctulatus* group. Thus the coastal regions of the Philippines have been relatively free of endemic malaria as compared with hill sections. The speculation arises naturally as to whether communication between the Philippines and the South and Southwest Pacific, by the Japanese and our people, may not introduce *punctulatus* and make a bad epidemiological situation worse. There would appear to be no climatic reason why *punctulatus* could not maintain itself, once established, at least in the southern islands of the Philippines.

Since the outbreak of the Sino-Japanese war there have been a series of epidemics throughout China. In the southwestern section of free China, *falciparum* infections predominate (Yao, 1943), and here the parasites are transmitted principally by *A. minimus minimus*. Elsewhere, particularly in the flat low-lying sections, *vivax* malaria is commonly found and has been responsible for annual autumnal epidemics in the vicinity of Chungking since 1939. There are no less than 25 species and six varieties of *Anopheles* mosquitoes in free China, of which *A. jeyporiensis var. candiensis* and *A. hyrcanus* var. *sinensis* are the most important aside from *minimus*, being found pretty much all over the country.

That northern India and Burma are intensely malarious is a fact which has been established by a large literature which has accumulated over a period of years. No recent papers of particular epidemiological significance have been available for review by the committee. In the absence of evidence to the contrary, it is assumed that there has been no material change in the circumstances relating to malaria transmission in this general region. It is believed that our troops operating in unsanitated parts of this area are exposed to infection, particularly with *P. falciparum*.

In the Caribbean area, a report by Bolton (1943) indicates that military forces in Puerto Rico developed infection rates as high as 3,000 per 1,000 per year in 1942 before control measures directed against *A. albimanus* could be established. In Trinidad, the general epidemiological problem has been defined by Downs, Gillette, and Shannon (1943). This study establishes *A. aquasalis* as the most important vector because of its bionomics. *A. bellator*, the only other proven vector, has a distribution limited by the occurrence of bromeliads because of its peculiar habit of breeding in the water collected by these epiphytes.

Inferences already formed by malariologists that extensive antimalaria programs in southern Europe have been abandoned during the war and that malaria is probably the most important communicable disease throughout this area are supported by the following reports. Petazzi (1942) states that there was an epidemic of *falciparum* malaria in the vicinity of Durazzo in 1940 and a considerable number of cases in 1941. The most important vector was probably *A. sacharovi*, and the decrease in 1941 seems to have been due to a dry season, increased salinity of coastal waters, and the efforts of a small force of civilian laborers and soldiers.

Coluzzi (1942) reports also that in the vicinity of Valona there was a sharp outbreak of *falciparum* disease in 1940. Coluzzi (1942) in another report states that there was widespread malaria in the Epirus region in Greece. The three common parasites were found. The author stresses an urgent need for the establishment of antilarval measures and the treatment of the sick in order to afford protection to travelers in the country.

It seems likely that Italy itself is sharing in the increase of malaria in southern Europe. On the basis of newspaper reports of progress of fighting in Sicily and Italy, it would seem that much of the important engineering work done for malaria control in the last twenty years has been destroyed by war, particularly in the area southwest of Rome. That malaria prevalence will increase to epidemic proportions in such situations seems almost inevitable.

The only recent available report on malaria in northern Europe appears as a note in Lancet for 30 September 1944. There has been a certain amount of endemic *vivax* malaria in the northern Holland for many years, although prior to 1940 the case rate was only a fraction of one per cent. This report states that there are 677 cases reported in 1941, 743 in 1942, 855 in 1943, and 1,019 for the first six months of 1944 with 576 cases reported in June alone. Nearly all of Zealand is now flooded and it is expected that approximately 8 per cent of the entire country will be flooded in time. When the salinity of flood waters falls to about 0.16 per

cent, it is to be expected that there will be a marked increase in the propagation of *A. atroparvus* with a commensurate increase in malaria transmission.

Russia also appears to be sharing in the increase in malaria prevalence that always accompanies and follows wars. Zumpt and Minning (1942), reporting on malaria in the Ukraine in 1942, described the malaria control work of the German military government. They report about 10 per cent of the population studied to be infected, principally with *P. vivax*, and mention what appears to be an unusual finding, namely, that the incidence of infections in persons over 30 years of age was nearly twice that in children under 10.

These sparse reports seem to emphasize two facts. (1) In the rehabilitation of countries where malaria has been a problem in the past, it is likely to present a problem as an epidemic disease; and where anophelism without malaria is present, malaria is likely to reappear. (2) Our troops in southern Europe, throughout the Orient, and the western Pacific will have to carry out an unremitting fight against malaria for the duration of the war.

While the war is in progress it seems evident that there will be an increasing number of naval and military personnel infected with malaria returning to contact with civilian populations in this country. Their distribution will be nation-wide and their number will increase sharply on demobilization. The possible results of the importation of malaria strains on the epidemiology of malaria in this country has been considered by Sisk (1943), Sawyer (1944), McCoy (1944), Mountin (1944), and Watson (1945). On the basis of evidence at hand and from logical inferences it would appear that most of these individuals will be infected with *P. vivax*. McCoy (1944) states that over 90 per cent of relapsed cases of malaria among returning troops are *vivax* infections. Assuming that there are as many infections with *falciparum* as with *vivax*, there is less chance of importation of *falciparum*. These infections are comparatively short lived and are more often cured by intensive treatment than *vivax*. For these and other reasons and because of the precarious existence of *falciparum* in the north temperate zone, the committee does not believe that the importation of *falciparum* infections is likely to influence considerably the epidemiology of malaria in this country. In this connection, however, a rather surprising report should be mentioned. Levenson, *et al* (1943), report many cases of malaria in the Archangel region of North Russia from infections apparently transmitted there. In some districts *falciparum* infections were more numerous than *vivax* infections. Since this district is about 60° north latitude, it would hardly be supposed that

the exogenous cycle could be completed (unless the adults live almost entirely indoors), and it is generally stated that endemic foci of *falciparum* in Russia do not occur north of the center of the country. If this report is to be taken at face value, it indicates the possibility of existence of *falciparum* strains which might conceivably be capable of endemic establishment in any of our northern states.

The probable impact of this new variable on the epidemiology of malaria in our country must await the conclusion of definitive studies now in progress. However, it seems reasonable to infer that at least some of the imported strains will prove to be transmissible by *Anopheles quadrimaculatus* and *A. freeborni.* If so, as a consequence malaria outbreaks may be expected to occur in situations where the disease has been unknown for a generation or more, unless control programs are formulated and put into operation. There is evidence that the programs proposed independently by Sawyer and Mountin at the last meeting of the Society are, in fact, being carried out, at least in some states.

The committee does not believe that the importation of malaria strains is likely to have a marked effect on the current downward trend of malaria in this country, although its influence may be felt for several years after demobilization.

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STATEMENT OF PROGRESS KENTUCKY RESERVOIR MALARIA CONTROL PROGRAM

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The malaria control program for the Kentucky Reservoir of the Tennessee Valley Authority was described in a report presented to the National Malaria Society by Bishop and Gartrell at the 1943 annual meeting (1). Because of the size, topography, and probable water level operating schedule, large scale permanent shoreline improvement measures were considered basic to a malaria control program which would meet the requirements of both effectiveness and operating economy. The program finally approved for this project included such permanent methods of preventing mosquito production as diking and dewatering and filling and deepening. In addition to the usual reservoir preparation practices of clearing and marginal drainage, restriction of land use to daytime occupancy was employed in one large part of the reservoir, and house mosquito proofing was used in areas where this method seemed indicated. Boat operating bases, airplane landing fields, and other facilities for application of larvicides were included in the pre-impoundage construction program.

Completion of the dam was originally scheduled for the winter of 1944-45, but due to the urgent need for power, the work was expedited and closure was made August 30, 1944. The demand for power made it necessary to fill the lake as soon as possible. Under the best of circumstances, summertime filling of a reservoir is undesirable from a malaria control standpoint, and in the case of the Kentucky Reservoir, because of the large area involved, it was not practical to prepare the area for flooding during the summer months. As an emergency measure, mosquito proofing of all dwellings was employed within the one-mile zone of the partial impoundage created during the late summer of 1944, with the approval of the public health departments concerned. Over one thousand dwellings were mosquito proofed and the methods and procedures developed for carrying out this program in a limited period of time are described fully in the paper being presented to the National Malaria Society by Kruse and Gartrell.

During the latter part of September, when the reservoir had reached elevation 343 ft., which is sixteen feet below normal pool elevation, extremely high densities of *A. quadrimaculatus* were present in the mile zone of the entire lower reservoir area. At this time, routine visits were made to the houses in the affected area, distributing five per cent pyrethrum insecticide and spraying houses where mosquitoes were present at the time of the visit, using dry-ice pressure spray units. This emergency house spraying gave considerable relief to the residents and served as a needed supplement to the mosquito proofing which was not completely effective in preventing entry of mosquitoes.

The final conditioning of the zone of malaria control drawdown, elevation 359 ft. to 354 ft., was deferred until the fall of 1944. Shortage of manpower necessitated more extensive use of machines. The principal developments on this operation, which was carried out by the Reservoir Clearance Division, was the more widespread use of mowing machines, both tractor and horse-drawn, and the use of a brush harrow. Approximately 20,000 acres of rebrushing was required to condition the five-foot zone of the reservoir. This work was begun July 15 and scheduled for completion December 1.

The construction of levees and pumping plants for the eight dewatering projects was completed. The eight concrete pumping plants ranged in size from 16,000 g.p.m. up to 250,000 g.p.m. with a combined capacity of 672,000 g.p.m. Two of the pumping plants are electric driven and the other six are gasoline driven. Approximately 1,618,000 cubic yards of earth were used for construction of approximately twenty-three miles of levee. Savings on clearing

and protection of highway and railroad fills more than offset the total cost of these malaria control projects.

The decision not to operate the pool above elevation 359 ft. during 1945, pending the completion of a major railroad crossing of the lake, made it possible for the Construction Department to schedule the malaria control deepening and filling projects for the summer and fall of 1944. Eight of these projects are nearing completion and have required the moving of approximately 1,500,000 yards of earth. The cut and fill procedure was followed on the major portion of all these projects, thus holding the amount of material handled to a minimum. The bulk of the work was handled by scrapers and bulldozers. Road patrols were used for final leveling of the fills, and draglines were used for construction of drainage ditches and excavation in areas too wet for other types of equipment. Approximately sixty-five miles of shoreline and 1600 acres of mosquito control problem flats between elevations 359 and 356 have been eliminated by this work. The filled portion of the areas are being seeded and prepared for subsequent use. In most instances, these projects are located in areas where grazing of the lake margins is being promoted to reduce annual growth removal operations.

Floating warehouses and boat slips for ten malaria control operating bases have been constructed in shops located at Wilson Dam, Alabama, and will be towed into place as soon as filling of the Kentucky Reservoir is completed. Grading of the harbors and base sites has been completed and boom-type anchorages have been installed for the floating facilities. A fleet of twenty-eight inboard larvicidal water oil units, twenty-two outboard utility hulls, and four inspection launches will be required for the larvicidal program. Four airplane landing fields have been constructed, and one dusting plane will be assigned to the Kentucky area with a reserve or supplementary unit stationed at Wilson Dam, Alabama. Two medium sized bulldozers and two small tractors have been included in the equipment for malaria control maintenance operations for use on minor permanent shoreline improvement work and drift removal. Two one-half-yard draglines will be used for drainage maintenance and construction.

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MALARIA MORTALITY AND MORBIDITY IN THE UNITED STATES FOR THE YEAR 1943*

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Introduction

A compilation of vital statistics year after year may be very prosaic or it may be utilized to vitalize certain trends in disease processes. This is as true for malaria statistics as for similar factual data concerned with any other disease. During the past twenty years the records on malaria mortality which have been compiled by state bureaus of vital statistics have been found to reflect rather faithfully the actual status of malaria in these particular political divisions of the United States[1 14]. On the other hand, when epidemiologists and statistical workers have attempted to collect similar data on malaria morbidity, with very few exceptions the results have been disappointing and the compilations have been essentially useless[6 13 14]. This has been due to several causes, among which the following may be named: (1) failure to make an accurate laboratory diagnosis of suspected cases of malaria or to make any accurate diagnosis at all; (2) self-treatment of many cases with quinine, usually with inadequate amounts of the drug and frequently in the form of a proprietary tonic; and (3) failure of many physicians to keep accurate records of patients diagnosed either by clinical or laboratory methods. Only during the past three years has there been an indication in the morbidity records for malaria that laboratory diagnosis is beginning to find a real place in determining the etiology of the disease and that physicians, in cooperation with state directors of health, are becoming more aware of the need for making accurate diagnosis and for keeping faithful records.

This year, in compiling the data on malaria for 1943, a request has been made of state public health officials for the following information:

(1) Malaria deaths by counties and total for the State.

(2) Reported cases of malaria by counties and total for the State.

*Report of the Committee on Vital Statistics to the National Malaria Society, St. Louis, Missouri, 16 November 1944.

(3) Relative percentage of *vivax, falciparum* and quartan infections determined by laboratory examination of suspected blood films.
(4) Deaths reported in question (1) due to therapeutic use of malaria parasites.
(5) Number of malaria deaths or cases among drug addicts.
(6) Deaths or cases reported in questions (1) and (2) among military personnel in service or among those who had been in such service.

Although follow-up requests were necessary on over half of the inquiries sent out, adequate replies on question (1) were received from forty-seven states, New York City and the District of Columbia; on question (2), from forty-six states, New York City and the District of Columbia; on question (3) from twelve states, New York City and the District of Columbia; on questions (4) and (5) from ten states, New York City and the District of Columbia, and on question (6), from thirty states, New York City and the District of Columbia. The most important information resulting from a study of the records received is presented in this report.

Acknowledgments

We are grateful to officials of all state bureaus who have provided us with the information requested and particularly to those who have taken a personal interest in our problem and have included case history data on malaria deaths and illness contracted outside of the state in which they are residents, as well as new sources of infection which have recently come into the United States. Dr. Ludwik Anigstein kindly provided morbidity records for thirty-three East Texas counties, and the Division of Public Health Methods, U. S. Public Health Service, the case reports by counties for Arizona. We are also indebted to Mrs. Anne Richards and Miss Fay Gill, Department of Tropical Medicine, Tulane University, for loyal and intelligent secretarial assistance during the process of assembling and collating the records.

Presentation of Data

Mortality Data.—The total number of reported malaria deaths in the civilian population for 1943 was 622, providing a rate of 0.47 per 100,000 population. Ninety-two and six-tenths per cent of these deaths was among residents in the Southern States, compared with 80 per cent in 1941.[13] The 1943 rate represents 26 per cent decrease of total malaria deaths from 1942,[14] 55.3 per cent from 1941[13] and 55.7 per cent from 1940.[12] With one exception, in each of the states for which the rates are statistically significant

the decline has been practically as great as, or even greater than, that for the entire country during this four-year period. For Alabama the malaria deaths for 1940, 1941, 1942 and 1943 were respectively, 197, 120, 94, 60; for Arkansas, 179, 163, 118, 108; for Florida, 99, 85, 48, 41; for Georgia 89, 75, 76, 37; for Illinois, 18, 8, 15, 9; for Indiana, 12, 6, 8, 6; for Kentucky, 18, 17, 12, 13; for Louisiana, 86, 71, 60, 29; for Mississippi, 169, 146, 84, 74; for Missouri, 43, 25, 20, 25; for North Carolina, 61, 32, 33, 21; for South Carolina, 128, 126, 100, 62; for Tennessee, 62, 50, 29, 21; and for Texas, 161, 148, 91, 54. The single state in which a proportionate decrease has not occurred is Oklahoma. in which the corresponding figures were 23, 52, 23, 30.

No deaths due to malaria locally acquired were reported from Arizona, Colorado, Connecticut, Delaware, the District of Columbia, Idaho, Iowa, Kansas, Maine, Massachusetts, Minnesota, Montana, Nebraska, New Jersey, North Dakota, Oregon, South Dakota, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin and Wyoming. In the remaining twenty-five states the number of counties in which indigenous malaria deaths occurred in the civilian population compared with the total number of counties in the respective states is represented by the following ratios: Alabama, 30:67; Arkansas, 36:75; California, 3:58; Florida, 26:67; Georgia, 37:159; Illinois, 7:102; Indiana, 4:93; Kentucky, 10:120; Louisiana, 16:64; Michigan; 2:83; Mississippi, 34:82; Missouri, 14:114; Nevada, 1:17; New Mexico, 1:31; New York, 4:57; North Carolina, 14:100; Ohio, 4:88; Oklahoma, 17:77; Pennsylvania, 1:67; Rhode Island, 1:5; South Carolina, 21:46; Tennessee, 17:95, and Texas, 31:238. For the entire United States deaths from malaria among the resident civilian population occurrred in 331 of the 2964 counties or 11 per cent of the total number of political subdivisions of the 48 states.

In past years the senior writer has based his reports on the intensity of malaria in the more highly malarious states primarily on the mortality rates for counties or groups of contiguous counties within a state. For 1943 the record indicates that in Alabama no county had a rate in excess of 15 per 100,000; in Arkansas, *Lincoln Co.* had a rate of 35.5 and no other county in excess of 15; in Florida, Indian River Co. had a rate of 22.2, Lafayette Co. 22.7, *Liberty Co.* 26.3 and *Suwannee Co.* 29.2; in Georgia, Pulaski Co. had a rate of 20.4 and all others were relatively low; in Louisiana, no parish had a rate as high as 15; in Mississippi, the counties with the highest rates were *Quitman,* with 33.1, and Bolivar, with 14.8; in Missouri, the malarious southeastern counties with relatively high rates were *Ripley,* with 39.7; Butler, with 20.4 and Pemiscot, with 8.5; in North Carolina, *Washington Co.,* on Albemarle Sound, had a rate

of 40.7; in Oklahoma, McCurtain Co. had a rate of 16.9; Choctaw Co., 10.6, McIntosh Co., 8.3 and Pittsburg Co., 8.2; in South Carolina, Collenton Co. had a rate of 22.8, Clarendon Co., 19.0, Beaufort Co., 18.2, Orangeburg Co., 15.7 and all others under 15; in Tennessee, the highest rate was 8.2, for Lauderdale Co., and in Texas, *Donley Co.* had a rate of 26.7, the only one in excess of 10. Thus, in 1943, there was a total of seven counties (all indicated by italics) with a rate in excess of 25. None of these counties had similarly high rates in 1942, and only one, Lincoln Co. Arkansas, was in the group in 1941. A rate of 25 or more existed in three more counties in 1943 than in 1942. These figures indicate considerable fluctuation in the hyperendemic regions from year to year.

Morbidity Data.—For the first time in these annual reports an attempt has been made to plot the morbidity data by counties as a supplement to the mortality figures. Even though the case records are not particularly satisfactory *per se,* a correlation of the two types of data has been found to be distinctly useful. When several deaths and many cases coexist in the same county or in the same block of counties, there is substantial evidence that the particular area is hyperendemic. This is indicated, for example, throughout many contiguous counties in southeastern South Carolina. The combination of these two types of data also tends to show how malaria spreads out marginally from hyperendemic foci, as from the coastal areas of the Carolinas into the lower Piedmont levels, up the river valleys of Virginia, and in the Sacramento River valley in California. Moreover, it provides provisional evidence of numerous scattered, mildly endemic areas. A discrepancy in the records exists in certain areas of Florida, Kentucky, southeastern Missouri and in several smaller foci in other states, where deaths are frequently allocated to counties for which no cases have been reported. Similarly, cases have been reported from several counties where it seems improbable that malaria exists endemically today.

If the morbidity records may be regarded as having suggestive value, we have for the first time an over-all picture of the geographical extent of malaria in the civilian population of the United States as of 1943.

For several years, the states on the Atlantic Seaboard north of the Potomac River and certain North Central States have meticulously attempted to trace to their origin the cases of malaria diagnosed within their borders. This is both good propaganda and good public health intelligence. The efficiency of the machinery is particularly indicated in the reports provided by Massachusetts, Rhode Island, New York (and separately, New York City), Pennsylvania, New Jersey, Maryland, Illinois, Minnesota and Wisconsin.

In certain Southern states which are still rather highly malarious, recent statewide blood-film surveys indicate the extensive distribution of the disease. Thus, in Mississippi, where intensive diagnosis surveys were carried out by the State Board of Health in 1943, 25,094 malaria-positive bloods (13,480 from whites, 11,614 from negroes) included samplings from every county in the state. On the basis of these figures the state malaria rate is given as 1.12 per cent. Moreover, a statewide blood-film survey was conducted during 1937-1942 in North Carolina. It included 82,616 films made and examined, of which one per cent was malaria-positive. Again, in South Carolina 9,866 blood films taken in 1943 were positive for malaria, providing evidence that 44 of the 46 counties had persons harboring the malaria parasites, with a state rate of 0.51 per cent. In view of the higher malariousness of South Carolina compared with North Carolina during the past decade, it seems entirely probable that the reported South Carolina index should be doubled, tripled or even quadrupled in order to provide an index of the actual malariousness of the state. The above figures, inadequate as they are, suggest that at least a one per cent incidence of malaria exists today throughout a considerable portion of the Southern states. The population of this area amounts roughly to 30,000,000 and the samplings of malariousness point to a minimum of 300,000 civilians who have the disease.

Types of Malaria Parasites Involved.—The information obtained from the state authorities interrogated is entirely inadequate to give a comprehensive picture of the species of parasites involved. In Illinois, *vivax* infection predominated (50 per cent) in the laboratory diagnosed infections, but *falciparum* and quartan types were encountered. In New Jersey, the cases were usually *vivax.* Of 61 civilian cases diagnosed in New York City, 27 were *vivax,* 19 *falciparum,* 5 quartan, one mixed *vivax* and *falciparum* and 9 of undetermined type. In the North Carolina survey (1937-1942), *vivax* was diagnosed 391 times, *falciparum* 385 times, quartan twice and mixed infections twice. In Alabama, the laboratory diagnosis for 1943 consisted of 204 positive films, of which 172 were vivax, 24 *falciparum,* none quartan and 18 unclassified. In Arkansas, of the 108 laboratory diagnosed films 11 were *vivax,* 7 *falciparum,* one quartan and 89 unclassified. In California, of 95 laboratory diagnosed films 72 were *vivax,* 11 *falciparum,* 4 quartan and 7 unclassified. In Florida, of 57 laboratory diagnosed films 51 were *vivax,* 5 *falciparum* and one unclassified. In Georgia, the total number of laboratory-diagnosed films is not reported but the percentages are stated to be as follows: *vivax,* 37.7 and *falciparum,* 62.3, with no diagnosis of quartan malaria. In Iowa, all of the 16

diagnosed cases were *vivax*. In Massachusetts, *vivax* was most frequently encountered and in Michigan, all state laboratory diagnoses were *vivax*. In Mississippi, the Director of the Division of Preventable Disease Control had no information on the species of malaria parasites from the 25,094 laboratory-diagnosed cases of infection reported for 1943. In Tennessee, of 208 diagnosed cases 127 were *vivax*, one *falciparum*, two quartan and 78 unclassified. In summary, it may be concluded that in most states, particularly in the north, *vivax* infection predominates, with *falciparum* second and quartan occasionally encountered. Nevertheless in North Carolina *vivax* and *falciparum* were equally prevalent and in Georgia *falciparum* was 1.65 times as commonly diagnosed as *vivax*.

Deaths from Therapeutic Malaria and in Drug Addicts.—Most state departments of health have no information concerning deaths due to malaria used as a therapeutic agent. Probably in the majority of states, as specifically pointed out by the state epidemiologist, such deaths are certified under the disease for which the malaria parasites were administered. However, it seems relatively certain that none of the basic mortality data utilized in this report include therapeutic accidents.

Information on malaria contracted by one drug addict from another through the use of a common hypodermic syringe is not commonly available in the state statistical files. In 1943 one *falciparum* infection of this type was reported from the District of Columbia, while New York City had four recorded new cases and two recurrent ones. Undoubtedly the actual number seen in the charity hospitals and clinics of the larger cities is several fold the few instances cited.

Malaria Acquired Overseas.—It is already common knowledge that our military forces in malarious areas overseas have had to combat malaria as a major obstacle. At first the morbidity was very high, as might be expected when a group of non-immunes enters a hyperendemic region. However, the situation was speedily improved as a result of suppressive treatment coordinated with the efforts of malaria survey and malaria control units of the armed forces of the United States and Allied Countries. With few exceptions *falciparum* malaria was eliminated as a disease problem with the institution of a moderately high, but well tolerated atabrine blood level, but *vivax* malaria has tended to recur persistently as soon as antimalarial therapy is discontinued. A large number of these *vivax* patients has been returned to the United States and for years to come will constitute a potential hazard, particularly if the exotic strains of the plasmodia which they harbor are picked up by

our indigenous *Anopheles* mosquitoes and develop in them to the stage infective for man.

The exact rates for malaria acquired by troops overseas as well as by those who have not been outside the Continental United States " cannot be quoted for publication or for dissemination at public discussions," although a chart recently released by the Office of the Surgeon General, U. S. A.,[15] shows that the admission rate for home troops has been appreciably less than one per thousand since early in 1942, while that for the entire army overseas has fluctuated essentially under 50 per thousand, except for the year 1943 when it climbed for a time to slightly over 150.

With extraordinary skill and success the Army and Navy in their training camps in the United States have reduced malaria to an all-time low among their forces in malarious areas,[16] while the Division of Malaria Control in War Areas of the U. S. Public Health Service, cooperating with state health agencies, has provided moderately effective safeguards for the civilian population around the military establishments. Nevertheless, it is appropriate to inquire what breaks in control may have occurred and what evidence state statisticians have of such occurrence. The records furnished us indicate that at several ports of entry into the United States or later, following travel inland, many cases and a few deaths resulting primarily from malaria acquired overseas have come to the attention of state departments of public health and private physicians. The personnel diagnosed include Army and Navy forces, either on request made by military officers or when the individuals were on furlough at home; veterans of World War II who have returned to civil life; prisoners of war, and seamen of the U. S. and Allied merchant marines. In addition, civilians in considerable numbers have acquired malaria while serving as skilled or semi-skilled laborers in military projects overseas. Cases of malaria have been diagnosed in such individuals who reportedly were exposed to infection in Malta, Liberia, North Africa, South America, the Caribbean area, Mexico, the South Pacific, India and the Middle East. Thus, a considerable amount of malaria acquired outside the United States has already infiltrated into local communities, and an increasing amount may be anticipated during the next several years.

Transfusion as a Source of Malaria.—While this item is statistically unimportant, it constitutes a way in which malaria continues to be contracted. New York reports quartan acquired in 1943 from a donor who had the disease thirty years previously, and New York City records two cases of accidental transfusion, one in a one-month-

old infant whose donor was the father with a history of malaria twenty years earlier.

Discussion and Conclusions

A critical appraisal of the 1943 malaria data for the United States provide both hopeful indications and danger signals. The mortality rate for the entire country and that for the more highly malarious Southeastern United States is the lowest on record. As the more highly endemic area continues to contract, a greater proportion of deaths is confined to the South and, though the rates for these states as a whole are lower than previously, certain counties remain as foci of hyperendemicity. Moreover, in Oklahoma a recrudescence of moderately high malariousness is demonstrated for the eastern half of the state.

For most of the states the morbidity figures available are relatively valueless in themselves but in conjunction with the mortality figures have considerable significance. Viewed as a whole, the case records indicate the residual widespread coverage of malaria in the Carolinas, all of Georgia except the northeastern upland region, essentially all of Alabama, every county in Mississippi, practically all of Arkansas and much of Louisiana, the eastern half of Oklahoma and the eastern plains area of Texas. Moreover, appreciable indigenous malaria still exists in New Jersey, Maryland, the eastern river valleys of Virginia, in the Ohio and Mississippi river watersheds and in the Sacramento river valley in California. We have estimated on the basis of one per cent average malariousness in the more highly endemic Southern States that in this territory approximately 300,000 persons are infected. This figure is regarded as very conservative. Possibly an additional 100,000 civilians outside this area also harbor infections, so that the total infected population is at least 400,000. For the South this probably means about one malaria death per 500 cases and for the remainder of the country, one death per 1000 or more cases. The difference in ratios is accounted for by the relatively uncommon occurrence of indigenous *falciparum* malaria north of the Ohio River.

The danger signals in malaria in the United States arise from the following causes: (1) The persistence of extensive mother foci of malaria throughout the Southeastern States and extending into eastern Oklahoma and the East Texas plains, where there is evidence of more active infection than a few years ago; (2) the return of *vivax*-infected military personnel to home communities, either on furlough or after return to civilian life; (3) the presence of infected prisoners of war in malarious localities or those in which susceptible *Anopheles* mosquitoes breed; (4) the return of infected merchant seamen and civilians from overseas duty into home com-

munities; (5) the existence of malaria among drug addicts, especially in the larger cities, where small epidemics of malaria may develop without the intervention of the mosquito transmitter, and (6) the increasing possibility of malaria being contracted from blood transfusion, even when inapparent cases serve as donors.

The above conclusions are interpretations of the senior writer, based on the statistical data which have been furnished to him annually over a period of thirteen years by the respective state bureaus. The data might be more optimistically appraised by some analysts but wisdom lies in facing the problem and combatting it. To this end there is need in every state for more critical and more extensive laboratory diagnosis of suspected malaria cases, and a rigid distinction between introduced and locally acquired infections in the more malarious states, such as is made in several of the non-malarious or lightly malarious ones. While military and public health officials have minimized the likelihood of malaria being transferred from civilian to military populations in the Continental United States and reciprocally have greatly reduced the danger of civilians contracting the disease from military sources, the controls are not fool-proof, particularly with the return of large numbers of *vivax*-infected individuals from overseas hyperendemic areas[17], [18]. Again, the propagation of malaria in drug addicts appears to be inadequately notified in the majority of states and their political subdivisions. Finally, individual physicians should be informed of the greater hazard of contracting malaria as a result of blood transfusions.

Summary

1. This report is based on information furnished by the bureaus of vital statistics of the respective states of the United States, New York City and the District of Columbia, and includes both mortality and morbidity data for the year 1943.
2. The mortality data provide evidence of the increased reduction of deaths over previous years, with a reported total of 622 (rate 0.47 per 100,000 population for the whole United States), of which 92.6 per cent is allocated to the more highly malarious South.
3. The morbidity data are still relatively unsatisfactory but in combination with mortality figures add to the general picture of malariousness, particularly its continued prevalence in the Southern States. Based on certain state-wide blood-film surveys it is estimated that in the more highly malarious Southern States there is a minimum of 300,000 infected individuals in this territory and probably an additional 100,-

000 in the civilian population of the remaining, more mildly endemic territory.

4. Cases and deaths due to therapeutic malaria are not usually notified as such to state departments of health and the majority of departments have no information on this item. Malaria in drug addicts is specifically noted by very few state bureaus of vital statistics.
5. Considerable attention is paid to malaria contracted overseas which is diagnosed in the non-malarious or lightly malarious states, but in the majority of the more highly malarious states machinery has not been developed to distinguished between malaria contracted by resident civilians within the state and malaria which may have been acquired overseas or outside the state.
6. Based on the 1943 malaria statistics, for which previous annual compilations have served as a background, certain suggestions are made with a view of reducing the prevalence and hazards of the disease in the United States. These recommendations include more extensive laboratory diagnosis of suspected cases, more rigid distinction between locally and exotically acquired malaria, more general notification of the disease among drug addicts and greater precautions against transferring the malaria parasites through blood transfusions.

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INDICES FOR VOLUMES I TO III

Indices and title pages are now being prepared for Volumes I to III of the Journal of the National Malaria Society. In the future, it is planned to include an index and title page with the last issue of each volume. Volumes I and II will be indexed together since they include only three numbers and a supplement.

Indices will be sent as early as possible to subscribers and members who received copies of the Journal at the time each volume was published.

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The supply of early issues of the Journal of the National Malaria Society is exhausted. Larger editions are being printed of current numbers but it will not be possible for libraries to complete their sets unless some individual subscribers, who do not wish to maintain a personal library, offer to sell copies of the early issues to the Society. Communications in this regard should be addressed to the Secretary-Treasurer who will buy, at his discretion and indicated prices, copies of the following back issues of the Journal: Volume I, \$2.00; Volume II, number 1, \$1.00; Supplement to Volume II, number 1, \$0.50; Volume III, numbers 1 and 2, \$0.50 each.